Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Supporting Air and Space Expeditionary Forces. Analysis of CONUS Centralized Intermediate Repair Facilities**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rand Corporation,1776 Main Street,PO Box 2138,Santa Monica,CA,90407-2138**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**274**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

This product is part of the RAND Corporation monograph series. RAND monographs present major research findings that address the challenges facing the public and private sectors. All RAND monographs undergo rigorous peer review to ensure high standards for research quality and objectivity.

Supporting Air and Space Expeditionary Forces

Analysis of CONUS Centralized Intermediate Repair Facilities

Ronald G. McGarvey • James M. Masters • Louis Luangkesorn
Stephen Sheehy • John G. Drew • Robert Kerchner
Ben Van Roo • Charles Robert Roll, Jr.

Prepared for the United States Air Force

Approved for public release; distribution unlimited

RAND PROJECT AIR FORCE

The research described in this report was sponsored by the United States Air Force under Contracts FA7014-06-C-0001 and F49642-01-C-0003. Further information may be obtained from the Strategic Planning Division, Directorate of Plans, Hq USAF.

Library of Congress Cataloging-in-Publication Data

Supporting air and space expeditionary forces : analysis of CONUS centralized intermediate repair facilities / Ronald G. McGarvey ... [et al.].
p. cm.
Includes bibliographical references.
ISBN 978-0-8330-4290-3 (pbk. : alk. paper)
1. United States. Air Force—Supplies and stores. 2. Airplanes, Military—United States—Maintenance and repair. 3. United States. Air Force—Facilities. I. McGarvey, Ronald G. II. Title: Supporting air and space expeditionary forces, analysis of CONUS CIRFs.

UG1123.S88 2008
358.4'183—dc22

2008035565

Published 2008 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
RAND URL: http://www.rand.org
To order RAND documents or to obtain additional information, contact Distribution Services: Telephone: (310) 451-7002;
Fax: (310) 451-6915; Email: order@rand.org

Preface

This monograph describes a series of analyses performed for the United States Air Force (USAF) and sponsored by the Deputy Chief of Staff for Installations and Logistics (AF/IL).[1] These analyses focused on designing a set of networks of Centralized Intermediate Repair Facilities (CIRFs) that would provide centralized off-equipment repair of major aircraft components in the continental United States (CONUS). The premise for the investigation was that well-designed CONUS CIRF networks could provide maintenance support more efficiently and effectively than can the traditionally used procedures, which generally rely on decentralized, or local, maintenance facilities. Although the USAF has experience with operating CIRFs in both the CONUS and overseas, Air Force leadership did not have an analytic method for designing cost-effective CIRF networks or readily comparing alternative potential network designs. The RAND Corporation was asked to develop such an approach and to perform the analyses.

This monograph describes the new modeling approach developed to construct the CONUS CIRF network designs and presents detailed results from the specific analyses. The analyses are based on F-15, F-16, and A-10 aircraft force structure bed-downs resulting from the Defense Base Closure and Realignment Commission's 2005 recommendations. For the three aircraft types, all CONUS active duty bases, Air National Guard (ANG) installations, and Air Force Reserve Command (AFRC) installations possessing combat-coded or training aircraft, along with

[1] The current title of this office is Deputy Chief of Staff for Logistics, Installations and Mission Support (AF/A4/7).

some Air Force Materiel Command (AFMC) bases, were used as locations to be supported by CIRF networks. CIRF network designs were constructed for aircraft engines (TF34, F100, F110), electronic warfare (EW) pods (ALQ-131, ALQ-184), Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) navigation (AN/AAQ-13) and targeting pods (AAQ-14s), and F-15 avionics line replaceable units (LRUs). This set of commodities was chosen because previous analyses (many of which were performed at RAND) had suggested that they afforded the largest potential savings from consolidated maintenance. Tasking scenarios considered in these analyses included normal peacetime training and readiness, Air and Space Expeditionary Force (AEF) deployment taskings, and major regional conflict (MRC) taskings. The research, completed in March 2006, was conducted within the Resource Management Program of RAND Project AIR FORCE as part of a research project, begun in fiscal year 2005, titled "CONUS CIRF Implementation Analysis."

This monograph should be of interest to such functional-area subject matter experts as combat support planners, logisticians, mobility planners, and operations planners; leaders and key staff officers at the Headquarters Air Force, Major Command, and operational levels; maintenance personnel; and operators throughout the Department of Defense (DoD), especially those in the ANG, Air Force Reserve, and active duty Air Force.

This monograph is one in a series of RAND reports addressing agile combat support (ACS) issues in implementing the AEF. Related publications include the following:

- *Supporting Expeditionary Aerospace Forces: An Integrated Strategic Agile Combat Support Planning Framework*, Robert S. Tripp et al. (MR-1056-AF). This report describes a framework for integrated combat-support planning that may be used to evaluate support options on a continuing basis, particularly as technology, force structure, and threats change.
- *Supporting Expeditionary Aerospace Forces: New Agile Combat Support Postures*, Lionel Galway et al. (MR-1075-AF). This report describes how alternative resourcing of forward operating loca-

tions can support employment timelines for future AEF operations. It finds that rapid employment for combat requires some prepositioning of resources at forward operating locations.
- *Supporting Expeditionary Aerospace Forces: An Analysis of F-15 Avionics Options*, Eric Peltz et al. (MR-1174-AF). This report examines alternatives for meeting F-15 avionics maintenance requirements across a range of likely scenarios. It evaluates investments for new F-15 avionics intermediate shop test equipment against several support options, including deploying maintenance capabilities with units, performing maintenance at forward support locations (FSLs), and performing all maintenance at the home station for deploying units.
- *Supporting Expeditionary Aerospace Forces: A Concept for Evolving to the Agile Combat Support/Mobility System of the Future*, Robert S. Tripp et al. (MR-1179-AF). This report describes the vision for the ACS system of the future based on individual commodity study results.
- *Supporting Expeditionary Aerospace Forces: Expanded Analysis of LANTIRN Options*, Amatzia Feinberg et al. (MR-1225-AF). This report examines alternatives for meeting LANTIRN support requirements for AEF operations. It evaluates investments for new LANTIRN test equipment against several support options, including deploying maintenance capabilities with units, performing maintenance at FSLs, and performing all maintenance at CONUS support hubs for deploying units.
- *Supporting Expeditionary Aerospace Forces: Lessons From the Air War Over Serbia*, Amatzia Feinberg et al. (not available to the general public). This report describes how the Air Force's ad hoc implementation of many elements of an expeditionary ACS structure to support the air war over Serbia offered opportunities to assess how well these elements actually supported combat operations and what the results imply for the configuration of the USAF ACS structure. The findings support the efficacy of the emerging expeditionary ACS structural framework and the associated but still-evolving USAF support strategies.

- *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance*, Mahyar A. Amouzegar et al. (MR-1431-AF). This report evaluates the manner in which jet engine intermediate maintenance (JEIM) shops can best be configured to facilitate overseas deployments. It examines a number of JEIM support options, which are distinguished primarily by the degree to which JEIM support is centralized or decentralized. See also *Engine Maintenance Systems Evaluation (En Masse): A User's Guide*, Amouzegar and Galway (MR-1614-AF).
- *A Combat Support Command and Control Architecture for Supporting the Expeditionary Aerospace Force*, James Leftwich et al. (MR-1536-AF). This report outlines the framework for evaluating options for combat support execution planning and control. It describes the combat support command-and-control operational architecture as it is now and as it should be in the future. It also describes the changes that must take place to achieve that future state.
- *Reconfiguring Footprint to Speed Expeditionary Aerospace Forces Deployment,* Lionel A. Galway et al. (MR-1625-AF). This report develops an analysis framework—as a footprint configuration—to assist in devising and evaluating strategies for footprint reduction. It attempts to define footprint and to establish a way to monitor footprint reduction.
- *Analysis of Maintenance Forward Support Location Operations*, Amanda Geller et al. (MG-151-AF). This monograph discusses the conceptual development and recent implementation of maintenance forward support locations (also known as CIRFs) for the USAF. The analysis focuses on the years leading up to and including the AF/IL CIRF test, which tested the operations of CIRFs in the European theater from September 2001 to February 2002.
- *Supporting Air and Space Expeditionary Forces: Lessons from Operation Enduring Freedom*, Robert S. Tripp et al. (MR-1819-AF). This report describes the expeditionary ACS experiences during the war in Afghanistan and compares them with those associated with Joint Task Force Noble Anvil, the air war over Serbia. It analyzes how ACS concepts were implemented, compares current

experiences to determine similarities and unique practices, and indicates how well the ACS framework performed during these contingency operations. The analysis can be used to update the ACS framework to better support the AEF concept.

- *Supporting Air and Space Expeditionary Forces: A Methodology for Determining Air Force Deployment Requirements,* Don Snyder and Patrick Mills (MG-176-AF). This monograph outlines a methodology for determining manpower and equipment deployment requirements. It describes a prototype policy analysis support tool based on this methodology, the Strategic Tool for the Analysis of Required Transportation (START), that generates a list of capability units, called unit type codes (UTCs), required to support a user-specified operation. The prototype also determines movement characteristics. A fully implemented tool based on this prototype should prove to be useful to the USAF in both deliberate and crisis action planning.
- *Supporting Air and Space Expeditionary Forces: Lessons from Operation Iraqi Freedom*, Kristin F. Lynch et al. (MG-193-AF). This monograph describes the expeditionary ACS experiences during the war in Iraq and compares them with those associated with Joint Task Force Noble Anvil in Serbia and Operation Enduring Freedom in Afghanistan. This monograph analyzes how combat support performed and how ACS concepts were implemented in Iraq, compares current experiences to determine similarities and unique practices, and indicates how well the ACS framework performed during these contingency operations.
- *Supporting Air and Space Expeditionary Forces: Analysis of Combat Support Basing Options,* Mahyar A. Amouzegar et al. (MG-261-AF). This monograph evaluates a set of global FSL basing and transportation options for storing war reserve materiel. It presents an analytic framework that can be used to evaluate alternative FSL options; a central component of the framework is an optimization model that allows users to select the best mix of land- and sea-based FSLs for a given set of operational scenarios, thereby reducing costs while supporting a range of contingency operations.

- *Unmanned Aerial Vehicle End-to-End Support Considerations,* John G. Drew et al. (MG-350-AF). This monograph presents the results of a review of current support postures for unmanned aerial vehicles and evaluates methods for improving current postures that may also be applied to future systems.
- *Strategic Analysis of Air National Guard Combat Support and Reachback Functions*, Robert S. Tripp et al. (MG-375-AF). This monograph analyzes transformational options for better meeting combat support mission needs for the AEF. The role the ANG may play in these transformational options is evaluated in terms of effective and efficient approaches for achieving the desired operational effects. Four Air Force mission areas are evaluated: CONUS CIRFs, civil engineering deployment and sustainment capabilities, GUARDIAN (an ANG information system used to track and control the execution of plans and operations, such as funding and performance data) capabilities, and air and Space Operations Center reachback missions.
- *A Framework for Enhancing Airlift Planning and Execution Capabilities Within the Joint Expeditionary Movement System*, Robert S. Tripp et al. (MG-377-AF). This monograph examines options for improving the effectiveness and efficiency of intra-theater airlift operations within the military joint end-to-end multi-modal movement system. Using the strategies-to-tasks framework, this monograph identifies shortfalls and suggests, describes, and evaluates options for implementing improvements in current processes, doctrine, organizations, training, and systems.
- *Supporting Air and Space Expeditionary Forces: An Expanded Operational Architecture for Combat Support Planning and Execution Control*, Patrick Mills et al. (MG-316-AF). This monograph expands and provides more detail on several organizational nodes described in earlier work that outlined concepts for an operational architecture for guiding the development of USAF combat support execution planning and control needed to enable rapid deployment and employment of the AEF. These combat support execution planning and control processes are sometimes referred to as Combat Support Command and Control (CSC2) processes.

RAND Project AIR FORCE

RAND Project AIR FORCE (PAF), a division of the RAND Corporation, is the U.S. Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is conducted in four programs: Force Modernization and Employment; Manpower, Personnel and Training; Resource Management; and Strategy and Doctrine.

Additional information about PAF is available on our Web site: http://www.rand.org/paf

Contents

Figures

Tables

Summary

In 2004, the United States Air Force Deputy Chief of Staff for Installations and Logistics, Lt Gen Michael E. Zettler, directed his staff to develop plans for the implementation of centralized intermediate repair facilities (CIRFs) to provide off-equipment repair of major aircraft components at a small number of regional facilities in the continental United States (CONUS). Failed aircraft components, such as engines or avionics, would be shipped from operating locations to CIRFs for repair, and serviceable replacements would be shipped from CIRFs to sustain the operating units. The logic behind the CIRF concept is simple. The CIRF operations, being larger than the traditional, local operations, would enjoy economies of scale and thus could be expected to handle the workload more economically—that is, with significantly less manpower. What was not yet well understood about this off-site maintenance concept, however, was how it would impact weapon system availability.

The RAND Corporation was asked to perform an analysis to determine whether CIRFs provide for cost-effective maintenance of CONUS fighter and attack aircraft. RAND had performed a number of CIRF analyses in past years, but these had all focused on the use of CIRFs outside the continental United States (OCONUS), primarily in support of Air and Space Expeditionary Force contingency operations. These analyses had a different motivation in that the attraction of an OCONUS CIRF is its ability to reduce the AEF's deployed footprint and increase the combat unit's flexibility and speed of deployment. However, because combat units would receive CIRF support when

deployed, adherence to the USAF doctrine to "train like you fight" would imply that units should also receive in-CONUS CIRF support for normal peacetime training.

This monograph describes the new modeling approach we developed to construct CONUS CIRF network designs. It also presents detailed results for specific analyses based on F-15, F-16, and A-10 aircraft force structure bed-downs that will result from the 2005 Defense Base Closure and Realignment (BRAC) process. For these three types of aircraft, all CONUS active duty bases, ANG installations, and AFRC installations possessing combat-coded or training aircraft, along with some AFMC assets, were included as locations to be supported by the CIRF networks. We constructed CIRF network designs for

- aircraft engines (TF34, F100, and F110)
- EW pods (ALQ-131 and ALQ-184)
- LANTIRN navigation (AN/AAQ-13) and targeting (AN/AQ-14) pods
- F-15 avionics LRUs.

Tasking scenarios considered in the analyses included normal peacetime training and readiness, AEF deployment taskings, and MRC taskings. The key ground rule for this study was that any increase in maintenance efficiency achieved by implementing CONUS CIRF structures could not come at the cost of a reduction in combat support capability (measured as a mission capable rate or serviceable spare component level).

From our many analyses of CONUS CIRF implementation options across a range of individual commodities, force structure bed-down assumptions, and operational scenarios, we developed general findings and policy recommendations on the employment of the CONUS CIRF concept, as well as more-specific findings and recommendations on particular commodities and implementation details. Our general findings are as follows:

1. CONUS CIRF is a cost-effective maintenance strategy. In most cases examined, we found the CONUS CIRF concept to be cost-effective. By this we mean that for the scenarios and commodities we evaluated, centralized maintenance networks outperformed decentralized maintenance networks in terms of weapon system availability and cost in every instance but one (F-15 avionics).

2. Potential manpower cost savings more than offset increased transport costs. CONUS CIRF network solutions tend to substitute relatively inexpensive transportation costs for relatively expensive maintenance manpower. The costs of these asset transshipments are more than offset by the reductions in maintenance manpower costs that result from CIRF networks.

3. CONUS CIRF total pipeline requirements generally are not excessive. Pipeline asset requirements did not pose a problem in most implementation scenarios. New transport pipeline requirements are usually not large, and they are often offset by the reduction in awaiting maintenance (AWM) assets that results from centralized repair.

4. Many network designs are virtually equivalent in cost and performance. For each commodity and scenario studied, alternative CONUS CIRF network designs that differ only slightly in cost and performance can be developed. In other words, the specific situation often permits a great deal of flexibility in the choice of network to be implemented.

5. Large user bases are naturally attractive CONUS CIRF locations. Bases that host large users of a commodity are prime candidates for a CONUS CIRF location (assuming all other variables are held constant) because of the resulting elimination of large transport pipelines. Most cost-effective CONUS CIRF networks call for CIRF facilities to be colocated at large user sites.

In addition to our general findings about the characteristics of well-designed CONUS CIRF networks, we offer the following specific, commodity-oriented findings related to CONUS CIRF implementation policies:

1. Spare engine pools are sufficient to support CONUS CIRF pipelines. Our analyses of TF34, F100, and F110 aircraft engines indicate that there are enough spare engine assets to adequately support the pipeline requirements for implementing the CONUS CIRF concept. (See pages 36–58.)

2. CONUS engine retained tasks are not cost-effective. The concept of CONUS retained tasks would allow operating bases that lose their full JEIM shops to retain a small capability for F110 and F100 engines, a capability sufficient to deal with a small subset of relatively "quick and easy" maintenance actions. Our analyses indicate that such retained tasks are not cost-effective for these engines. (See pages 42–46.)

3. F-15 avionics automatic test equipment (ATE) assets cannot support base-level bench check serviceable (BCS) screening. The BCS screening concept would allow F-15 units that lose their avionics intermediate-level maintenance (ILM) capability to retain ATE assets to screen for avionics LRUs that are removed at the flightline but for which the ATE finds no fault (a common occurrence). Our analyses suggest that F-15 avionics BCS screening is not cost-effective. Further, for the units we considered, there is insufficient inventory of certain ATE assets to support this concept. (See pages 89–92.)

4. F-15 avionics LRU spares pools are problematic. Many F-15 avionics LRUs are in critically short supply. The increased pipelines implied by CONUS CIRF implementation can be expected to increase the back-order situations for these assets. (See pages 83–92.)

5. CONUS CIRF network performance is sensitive to assumed removal rates and repair times. While our analyses support the CONUS CIRF concept for the commodities under consideration, the extent of CIRF savings is dependent upon several data factors for which significant uncertainty exists, such as wartime failure rates for pods and engine repair times. (See pages 52–58, 135–141.)

Overall, the results of this study strongly support both the feasibility and the desirability of using CONUS CIRF networks as a cost-effective maintenance policy for providing improved support to USAF warfighting forces at reduced levels of manpower and with lower total operating costs.

Acknowledgments

Many people inside and outside the U.S. Air Force provided valuable assistance and support to our analysis of CONUS CIRF networks. We thank former Air Force Deputy Chief of Staff, Installations and Logistics (AF/IL), Lt Gen Michael E. Zettler (Ret), for initiating this study. Lt Gen Donald J. Wetekam (Ret) provided insightful guidance and continued support as General Zettler's successor. We also offer special thanks to (all office symbols, titles, and ranks are listed as of the date of this study) Brig Gen P. David Gillett, AF/A4M; Col Steven Aylor and Col John Stankowski, AF/A4MM; and Col Elliot Worchester and Mr. Rich Rico of the National Guard Bureau for their guidance, strong support, and interest in this project. We extend a special thanks to the CONUS CIRF project Air Staff action officers: Maj Andrew Bauck, Lt Col Shawn Harrison, Maj Teresa Ainsworthy, Lt Col David Coley, and Mr. Lee Plowden. All of these individuals provided great support, insight, and timely guidance.

We are especially grateful to the major air command participants who brought their command views to the meetings and video teleconferences. In particular, we wish to thank the following people from across the Air Force for their hard work and candid discussions: Mr. Michael Hanson and Mr. John Ware, AF/ILGD; Ms. Betty Yanowsky, HQ DLA; Lt Col Glenn E. Roberts, ACC/LGMP; Mr. Florencio D. Garza, ACC/A4MA; Mr. Tom E. Smith, ACC/LGMP; MSgt Scott A. Holland, HQ ACC/A4MP; CMSgt Scotty Pyeatt, ACC/LGMP; Mr. Daniel R. Graham, ACC/A3IE; MSgt Kenneth C. Stevens, ACC/A4MA; SMSgt Jeffery P. Coddington, ACC/A4MA; MSgt Matthew

D. Regan, ACC/A4MA; MSgt Eric M. Petrucci, ACC/A8A15; MSgt Ty C. Elliott, ACC/DRA15; MSgt Michael L Razor, CMS/MXMV, Langley AFB; Mr. Woodrow R. Parrish, AFLMA/LGS; Mr. Malcolm E. Baker, WR-ALC/ITM; Mr. Robbie Ricks, WR-ALC/ITM; Mr. Jose G. Orsini, HQ AFMC/LSO; Mr. Carter McIntosh, OC-ALC/LR; Ms. Shannon G. Custard, OC-ALC/LPARA; Ms. Janice Eberhard, OC-ALC/LR; Mr. Robert E. Strong, OC-ALC/448 EPSG; Ms. Jane F. Neely, OC-ALC/LPRC; SMSgt Thomas A. Donaldson, HQ AFMC/LGM; Ms. Debra R. Galindo, 448 EPSG/IM; Mr. Bruce C. Eberhard, 448 EPSG/GBEAMA; CMSgt Tom Wolff, Propulsion Flight Superintendent, 20th Component Repair Squadron (CRS), Shaw AFB; and Mr. Alan J. Taylor, MXG/AFETS, Tyndall AFB.

We could not have conducted these analyses had it not been for the time and openness of the many Air Force logisticians we interviewed during our site visits. The support we received from these people—from senior leaders to airmen on the flightline—contributed immensely to our research.

Our research was a team effort with the Air Force Logistics Management Agency (AFLMA)—the support of the AFLMA was critical to the conduct of this research. We thank Col Ronne Mercer, AFLMA/CC; Capt James MacKenna, AFLMA/LGM; and CMSgt Tommy C. Rowell, AFLMA/LGM. Additionally, we would like to thank the RAND Corporation staff members who assisted in the writing, publication, and transmission of the various reports, messages, and other documents created during this study effort. We benefited greatly during the project from the comments and constructive criticism of many RAND colleagues, including (in alphabetical order) Mahyar Amouzegar, Laura Baldwin, Gary Massey, Mike Neumann, Ray Pyles, and Bob Tripp. We thank Amy Haas and Megan McKeever for their assistance in producing this document. We also thank our editor, Jeri O'Donnell, for her assistance, which greatly improved the presentation and readability of this document.

We would especially like to thank John Halliday and Keenan Yoho of RAND, along with Col Kenneth Lynn's staff at ACC/A4M, for their thorough reviews of this document, which helped shape it into its final, improved form.

As always, the analysis and conclusions are solely the responsibility of the authors.

Abbreviations

AB	Air Base
ACC	Air Combat Command
ACS	agile combat support
AEF	Air and Space Expeditionary Force
AETC	Air Education and Training Command
AF/IL	Deputy Chief of Staff for Installations and Logistics
AFB	Air Force Base
AFLMA	Air Force Logistics Management Agency
AFMC	Air Force Materiel Command
AFRC	Air Force Reserve Command
AIS	avionics intermediate system
AMC	Air Mobility Command
ANG	Air National Guard
ANT	antenna
APOD	aerial port of debarkation
ATE	automatic test equipment

ATP	advanced targeting pod
AWM	awaiting maintenance
AWP	awaiting parts
BCS	bench check serviceable
BIT	built-in test
BMRI	base maintenance removal interval
BRAC	Base Closure and Realignment
BSL	base stock level
C2	command and control
CEMS	Comprehensive Engine Management System
CIRF	Centralized Intermediate Repair Facility
CLS	Central Leveling Summary
CMRI	combined maintenance removal interval
CMS	component maintenance squadron
CND	cannot duplicate
CONOPS	concept of operations
CONUS	continental United States
COTS	commercial off-the-shelf
CRS	Component Repair Squadron
CSC2	combat support command and control
CSS	constant surveillance service
DDT	depot backorders/order rate
DLA	Defense Logistics Agency
DoD	Department of Defense

EARTS	Enhanced Aircraft Radar Test Station
ECM	electronic countermeasure
ESTS	electronic system test set
EW	electronic warfare
FMC	fully mission capable
FOL	forward operating location
FSL	forward support location
FY	fiscal year
HQ	Headquarters
ILM	intermediate-level maintenance
INT	in transit
INW	in work
JEIM	jet engine intermediate maintenance
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LIATE	LANTIRN intermediate ATE
LITENING	Laser Infrared Targeting and Navigating
LCOM	Logistics Composite Model
LMSS	LANTIRN mobility shelter set
LRU	line replaceable unit
MAJCOM	major command
MDS	mission design series
METRIC	Multi-Echelon Technique for Recoverable Item Control

MILP	mixed-integer linear programming
MRC	major regional conflict
MTBF	mean time between failures
MTBM	mean time between maintenance
MTTR	mean time to repair
NATO	North Atlantic Treaty Organization
NAV	navigation
NMCS	not mission capable, supply
NRTS	not repairable this station
OC-ALC	Oklahoma City Air Logistics Center
OCONUS	outside the continental United States
OEF	Operation Enduring Freedom
OHRI	overhaul removal interval
OIF	Operation Iraqi Freedom
PAA	Primary Aircraft Authorization
PAF	Project AIR FORCE
PDF	probability distribution function
PDM	programmed depot maintenance
PACAF	Pacific Air Forces
PCS	permanent change of station
PMI	periodic maintenance interval
PRS	Propulsion Requirements System
RAMPOD	Reliability, Availability, and Maintainability Data of Pods

RBL	Readiness Based Leveling
SDDC	Military Surface Deployment and Distribution Command
SRU	shop replaceable unit
START	Strategic Tool for the Analysis of Required Transportation
TEWS	Tactical Electronic Warfare System
TGT	targeting
TISS	AN/ALM-246 TEWS Integrated Support System
TO	Technical Order
UMD	Unit Manpower Document
USAF	United States Air Force
USAFE	United States Air Forces, Europe
WR-ALC	Warner Robins Air Logistics Center
WRE	war reserve engine
WRM	war reserve materiel
WRSK	War Readiness Spares Kit
XR	Sniper eXtended Range

CHAPTER ONE

The CONUS CIRF Concept

Introduction

The United States Air Force (USAF) expends a large percentage of its annual operating budget on the maintenance of its weapon systems. The USAF is acutely aware of the need to manage and operate these critical maintenance activities as efficiently as possible, and the RAND Corporation has worked with the USAF over several decades to improve the design and management of weapon system maintenance.

In 2004, the USAF Deputy Chief of Staff for Installations and Logistics, Lt Gen Michael E. Zettler, instructed his staff to develop plans for a sweeping change in the way the USAF performs aircraft maintenance in both peacetime and wartime. The initial plans would focus on changes affecting the fighter and attack aircraft operated in the continental United States (CONUS) by active duty Air Force units and by the Air National Guard (ANG) and Air Force Reserve Command (AFRC). One of those changes would involve the location of aircraft-component repair activities. A large number of component repair facilities, traditionally collocated with the flying unit at fighter bases, would be relocated and centralized into a much smaller number of larger and more efficient facilities. Failed aircraft components, such as engines and electronic warfare (EW) pods, would be shipped from operating-unit locations to these Centralized Intermediate Repair Facilities (CIRFs), and serviceable replacements would be shipped from CIRFs to sustain the operating units.

The motivation behind the CIRF concept is simple: larger facilities hold the promise of capturing economies of scale and thus could be expected to handle the workload more economically than can be done with the traditional, decentralized arrangement—that is, with significantly less manpower.

The USAF is moving toward a similar concept for the support of forces deployed outside the continental United States (OCONUS) in Air and Space Expeditionary Force (AEF) contingency operations. The motivation here is different, however: an OCONUS CIRF is attractive because it can reduce the AEF's forward-deployed footprint and increase unit deployment flexibility and speed. Thus, a further motivation for establishing CIRFs in CONUS is consistency with the USAF doctrine to "train like you fight": units that are to receive CIRF support when deployed would also receive CIRF support for normal peacetime training while in CONUS.

The CIRF concept is not new (Cohen et al., 1977). The USAF has used variations of it, such as the "Queen Bee" for engine repairs, since at least the Korean War (Geller et al., 2004). These centralized operations have usually been overseas, but there are CONUS-based examples as well, such as the current CIRF for TF34 engines at Shaw Air Force Base (AFB), which supports A-10 flying units at Pope and Eglin AFBs and at Spangdahlem Air Base (AB) in Germany.[1] What was being envisioned under Lt Gen Zettler's direction, however, was significantly different. Rather than having the occasional CIRF, usually in the OCONUS, the plan called for making CONUS CIRF support relationships the rule rather than the exception for a broad range of aircraft and components. The CONUS CIRF would become a standard way of doing business for component repair.

As mentioned above, the CONUS CIRF concept was seen as offering the promise of improved maintenance productivity. But before this concept could be deemed a wise choice, many important questions had to be answered. For example:

---

[1] Under current practice, A-10 units deploy with spare TF34 engines and use home station repair to replenish their spare stockpiles (although a small number of personnel may deploy to perform limited on-the-wing repair above and beyond normal home-station workloads).

1. Would the CONUS CIRF be able to provide a level of performance adequate for supporting wartime and peacetime missions and still provide increased efficiency?
2. Would the transportation costs of shipping assets to and from CIRFs outweigh the maintenance savings?
3. Would there be enough spare component assets to support the increased transport pipeline requirements?

A detailed and thoughtful analysis must be conducted to properly address these questions, comparing the costs and performance of the traditional, decentralized maintenance operations with those of a hypothetical CIRF's operation. However, it is not sufficient to consider only peacetime operations at CONUS units, since the CIRF network must be able to support deployed operations as well. Within our analysis, CIRF networks were evaluated against an unclassified notional sizing scenario in which 20 percent of the CONUS combat-coded aircraft deploy to a single unspecified theater, where they perform sustained operations for an indefinite period.[2] Full-time CIRF manning is defined as the requirement to support this deployment scenario. A major regional conflict (MRC) scenario, in which 50 percent of the combat-coded aircraft deploy to one theater and 50 percent deploy to another, was used to determine the requirement for part-time positions associated with the reserve component (AFRC and ANG).

For each of these deployment scenarios, we assumed that deployed aircraft were supported through some combination of an in-theater OCONUS CIRF and a CONUS CIRF. Those aircraft that are not deployed maintain their peacetime flying schedules and are supported at a CONUS CIRF. If an OCONUS CIRF is used, the additional workload attributable to the deploying aircraft is assumed to be accomplished by personnel deploying from the CONUS CIRFs.[3]

---

2 This deployment size was selected to be in accordance with the AEF construct, wherein one-fifth of the combat-coded units are prepared to deploy at any time.

3 Note that if a deployment occurs into a theater currently operating OCONUS CIRFs (e.g., the Pacific Air Forces [PACAF] F110 CIRF at Misawa AB), the requirement for deployment of manpower to the OCONUS CIRF would be less than the purely additive requirement because that CIRF's existing manpower would come into play. The desire to con-

The difference between the manning requirements for the MRC and the 20 percent deployment scenario constitutes the part-time manning requirement for each commodity.

Given the current system's large number of decentralized maintenance locations, many possible CONUS CIRF configurations, or CIRF network designs, each with its own costs and performance characteristics, could be implemented. To ensure that the evaluation identifies the true potential of the CONUS CIRF concept, the analysis should compare the best possible CIRF network configuration against current maintenance operations in terms of costs and performance.

To identify the best-performing CONUS CIRF network design for a given level of investment, one must be able to answer four fundamental questions. Provided a given commodity (such as an aircraft engine), a given bed-down of aircraft in CONUS, a given peacetime and wartime operating scenario, and a desired level of performance:

1. What is the appropriate number of CONUS CIRFs?
2. Where should they be located?
3. Which bases/units should be assigned to which CIRFs?
4. How big should each CIRF be?

RAND was asked to provide this identification. To answer these four questions, we developed a data-driven, analytic approach and a set of software tools and models that generate CONUS CIRF network designs. We also developed input databases and tasking scenarios for aircraft engines, pods, and selected avionics components for A-10, F-16, and F-15 aircraft fleets in CONUS. This monograph documents the development of our analytic approach and presents results and recommendations specific to the commodities we studied. The tools we developed are sufficiently robust to provide a useful general framework for analyzing commodities, scenarios, and weapon systems other than the ones we studied.

---

sider a scenario involving a single deployment to an unspecified theater precluded such an analysis.

Background

USAF Three-Level Maintenance Concept

The USAF generally provides for maintenance of a weapon system by organizing maintenance tasks and functions into three distinct levels, or echelons, of maintenance. In this context, *maintenance* means inspecting, fueling, arming, and servicing aircraft, as well as repairing and overhauling aircraft, aircraft components, and associated support equipment. As the names imply, *on-equipment maintenance* refers to maintenance work accomplished on the aircraft itself, and *off-equipment maintenance* means work accomplished on components that have been physically removed from the aircraft. The three levels of maintenance (independent of on- and off-equipment distinctions) are organizational, intermediate, and depot.

Organizational-level maintenance consists of routine sortie generation tasks, as well as the on-equipment servicing and repair of an aircraft, that are normally conducted on the flightline. An organizational-level repair action normally begins by identifying a failed aircraft component that is a line replaceable unit (LRU)—that is, an aircraft subassembly that flightline maintenance personnel are authorized to remove. The LRU is removed and replaced with a serviceable spare component, and the aircraft is returned to mission capable status.

Intermediate-level maintenance (ILM) traditionally consists of repairing failed LRUs that have been removed from a unit's aircraft through organizational-level maintenance actions. Each air base establishes ILM facilities, or "back shops," which are authorized to repair LRUs by removing and replacing failed shop replaceable units (SRUs) or by other means. LRUs made serviceable through this process are then returned to the base's spare parts inventory. Each base is authorized a specific quantity of spare LRUs and SRUs to support this "repair cycle" activity. ILM therefore generally consists of off-equipment component maintenance activity conducted on site—that is, at the aircraft operating location.

Depot-level maintenance is the major overhaul of aircraft through programmed depot maintenance (PDM), as well as the repair or overhaul of LRUs and SRUs. For any given aircraft or component, depot-level maintenance is usually accomplished at one central location—typically an Air Force Materiel Command (AFMC) Air Logistics Center (or depot) or a contractor facility, or sometimes a Navy or Army logistics facility. Additional spare LRUs and SRUs are authorized to support the maintenance and transport pipelines generated by the depot repair-cycle process. In addition, spare aircraft are authorized to support the PDM pipeline.

An example of this three-level process is as follows. Most air bases have a jet engine intermediate maintenance (JEIM) facility, or "engine shop." When a pilot reports an engine problem, organizational-level maintainers diagnose the problem. If a minor on-equipment repair is all that is needed to resolve the problem, they make the repair. If not, they remove the engine and replace it with a serviceable spare engine. The unserviceable engine is sent to the JEIM facility, where it is inspected and disassembled and where repair is normally accomplished by removal and replacement of a major subassembly (an SRU), such as a fan or compressor section. The engine is then reassembled, inspected, tested, and returned to the base's spare engine pool. The failed SRU is usually returned to the depot for overhaul or rebuild.

Logistics engineers conduct a repair level analysis during every weapon system's design phase. Each potential failure mode of each of the weapon system's components is examined in this analysis, and a cost/benefit determination decides whether a component failure mode is authorized as an organizational-, intermediate-, or depot-level repair action. Thus, in principle, the allocation of total maintenance workload among organizational-, intermediate-, and depot-level action is planned at the time the weapon system is designed, and is intended to optimize support for the weapon system. That is, maintenance actions are assigned to repair levels so as to minimize the total system costs of maintenance manpower, maintenance equipment, component transportation, and spare component pools necessary to provide a desired level of weapon system availability. In a typical three-level maintenance scheme, responsibility for and control of organizational- and intermediate-level maintenance activities are usually assigned to the aircraft's operating command, whereas depot-level maintenance becomes the responsibility of the AFMC.

In the context of the three-level maintenance concept, a CIRF simply represents a set of on-site, off-equipment component repair facilities being relocated and consolidated at an off-site component repair facility. The CIRF becomes a source of component supply to its supported operating locations, much like an AFMC Air Logistics Center or a Defense Logistics Agency (DLA) depot, albeit for a different set of components and maintenance tasks than those currently supported at AFMC and DLA depots.

Intermediate-Level Maintenance Deployment Concepts and Experience

An important consideration in designing a CONUS CIRF network is the need to provide ILM support to deployed forces. Increased CIRF workloads and lengthened asset pipelines would be expected as a result of deployments, and the CIRF itself might deploy in whole or in part to support deployed operations, depending upon the size of the deployment (e.g., AEF versus MRC requirements).

Throughout the Cold War era, the USAF developed maintenance concepts and detailed war mobilization plans to support deployed aircraft engaged in conventional combat operations. The primary focus of this planning for many years was for a major theater war in defense of the North Atlantic Treaty Organization (NATO) region, so planning focused on deploying fighter aircraft from CONUS to operate from NATO airfields. The plans were elaborate and detailed, but the basic maintenance support concept was straightforward. A squadron, the typical unit of deployment, would be tasked to deploy on relatively short notice to a pre-planned operating location in the theater, where it was intended to be self-sufficient for the first 30 days of combat operations. This meant that each squadron would deploy with its assigned aircraft, its aircrews and operational personnel, and its organizational-level maintenance personnel and equipment. In addition, it would deploy with a pool of war reserve materiel (WRM), including war reserve engines (WREs) and a War Readiness Spares Kit (WRSK). The levels of these spare engines and spare LRUs were calculated to satisfy the squadron's needs for the initial 30 days' worth of planned combat sorties. As a result, the flying unit could operate independently, without ILM or depot-level maintenance support, over that 30-day interval.

In some cases, the USAF recognized that 30 days' worth of LRU support in a WRSK could be a very expensive proposition. In the case of the F-15 avionics suite, for example, a determination made during the 1970s called for a deployed F-15 unit to operate with deployed ILM from the beginning of the deployment. The unit would deploy with its automatic test equipment (ATE), or avionics test stations, and their complement of avionics technicians, as well as with a two-day supply of LRUs and a 28-day supply of SRUs. While this led to a much lower investment in WRSK assets, the USAF recognized that this forward deployment of ILM capability in the early days of a contingency was far from ideal in terms of deployment footprint and unit flexibility. Since that time, the USAF has clearly preferred to reduce an engaged unit's dependence on its own component repair capability during the early stages of a deployment.[4]

For support beyond day 30 of the conflict, the Cold War era plans called for the base back-shop operations to deploy to the flying unit's forward location to provide ILM; that is, to do on-site component repair. Given the establishment of SRU pipelines between the deployed ILM activity and the depot facilities, this deployed ILM capability would have allowed the deployed flying units to operate for as long as might have been necessary. These plans even called for the follow-on deployment of relatively fixed facilities, such as JEIM shops and engine test facilities. In actual practice, however, full ILM support was rarely, if ever, deployed as follow-on support of contingency operations.

The AEF rotation policy that the USAF has chosen to employ over the last decade has separated deployment of specific aircraft from deployment of expeditionary combat support, which includes maintenance organizations. The exception is the Aircraft Maintenance

---

[4] As an example, F-15 avionics repair operates under a three-level maintenance concept; however, in the three most recent major contingencies (Operation Allied Force, Operation Enduring Freedom [OEF], and Operation Iraqi Freedom [OIF]), the USAF chose to provide F-15 avionics ILM from CIRFs in or near the theater of operations but remote from the operating locations (see Lynch et al., 2005).

Squadron—this organizational-level maintenance capability normally deploys with its assigned aircraft.

In actual practice, AEF rotational experience has involved support of extended deployed operations in Southwest Asia and elsewhere with minimal deployment of ILM personnel and equipment. Units deploy for 90 days or more with their aircraft, operators, and flightline maintenance. Rather than deploying full ILM personnel and equipment to the forward operating location (FOL) and then rotating them back as replacement units arrive, component pipelines are established to evacuate failed LRU assets and to resupply with serviceable spares. Component repair is variously accomplished at CIRFs in the region, at the unit's home station, at an Air Logistics Center, or at some other point in the general USAF logistics system.

There are several good reasons to provide LRU resupply in lieu of deployed ILM. For example, it would reduce the size of the deployment package, increasing the speed and ease of unit deployment and reducing the airlift requirement. It would also reduce the unit's forward deployment footprint and the support burden (billeting, medical, force protection, etc.) at the FOL,[5] which can be especially important because AEF operating locations tend to be austere environments where support is problematic.

Prior CIRF Studies and Analyses

The USAF has operated CIRFs for decades, and several previous RAND studies have considered CIRF issues and practices. For example, in the 1970s, RAND developed the Dyna-METRIC (Multi-Echelon Technique for Recoverable Item Control) model (Hillestad, 1982) to analyze the effect of spare parts inventories on support made available to flying units, particularly for tactical forces during the initial surge phase of deployed operations. The Dyna-METRIC model was an enhanced version of the METRIC model developed at RAND in the 1960s (Sherbrooke, 1968). Models of the METRIC type assess the

---

[5] One motivation for the PACAF CIRF initiative of the 1980s was the desire to move ILM workload from one-year, "short tour" permanent-change-of-station (PCS) bases to CIRFs at more-developed, three-year, "long tour" PCS locations.

expected performance of a logistics system composed of aircraft operating locations, pools of spares assets, transportation links, and component maintenance activities, both on-station ILM and off-station depot maintenance. Analyses using METRIC-like models require this predefined network of operating and maintenance locations as an input.

In the 1970s, RAND and the USAF developed detailed databases and operating scenarios to conduct analyses of tactical air forces in the Pacific region. Because the USAF used CIRFs in this theater to support engines and avionics, the Dyna-METRIC model was modified to include CIRF activities in its component repair network. Thus, it became possible to assess the performance of PACAF CIRF operations, and RAND analyses generally supported the notion that OCONUS CIRFs would provide increased support to these forces.

More recently, RAND has conducted multiple studies focused on the use of CIRFs at FOLs in AEF operations:

- Peltz et al. (2000) analyzed the consolidation of F-15 avionics ILM support operations for deployed aircraft and found that consolidated support policies would reduce total manpower requirements and increase deployment flexibility. They also found, however, that successful implementation of consolidated intermediate maintenance support would be contingent on quick establishment of a robust in-theater distribution capability.
- A similar study by Feinberg et al. (2001) focused on support of the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) system on deployed aircraft. It found that centralized in-theater maintenance operations produced superior results, again noting that CIRF system effectiveness would depend on reliable transportation and effective command and control (C2) systems.
- A third study, this one by Amouzegar, Galway, and Geller (2002), found support for the use of CIRFs for F100 and TF34 engines in both wartime and peacetime operations and cautioned against the policy of deploying JEIM facilities into the theater, instead recommending a system of centralized facilities in the theater or CONUS.

These studies compared the effectiveness of centralized wartime ILM operations with standard, decentralized ILM operations. In some cases, CONUS CIRFs were included in the analyses, but the studies did not focus directly on the key issues of CONUS CIRF network design—that is, on the appropriate number and location of CONUS CIRFs for these commodities. These studies thus pointed to the potential of the CONUS CIRF concept and, by doing so, opened the door to the work detailed in this monograph.

Preview of Findings

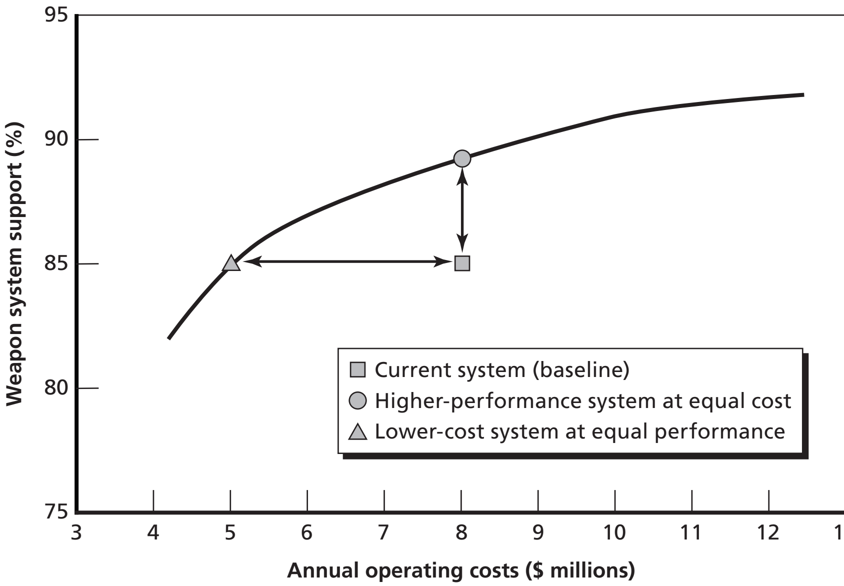
From our many analyses of CONUS CIRF implementation options across a range of individual commodities, force structure bed-down assumptions, and operational scenarios, we developed general findings and policy recommendations on the employment of the CONUS CIRF concept, as well as more-specific findings and recommendations on particular commodities and implementation details. These are briefly highlighted in the following sections.

General Findings

1. CONUS CIRF is a cost-effective maintenance strategy. In most cases examined, we found the CONUS CIRF concept to be cost-effective. The only exception was the F-15 avionics, in which case a shortage of critical LRUs led to degraded system performance (although at a significantly reduced cost) when maintenance was centralized. Our assessments, across a wide range of scenarios and commodities, show that centralized maintenance networks generally outperform decentralized maintenance networks. This idea is graphically demonstrated in the notional cost-performance tradeoff curve in Figure 1.1.

The gray square in this figure reflects the operating cost and weapon system support performance of a typical decentralized operation, with local ILM facilities at each aircraft operating location. The curve represents the set of efficient CONUS CIRF network configurations identified through our analytic procedure. Possible network

Figure 1.1
Notional Results of a Typical CONUS CIRF Commodity Analysis



RAND *MG418-1.1*

designs range from low-cost, low-performing configurations (toward the left side of the curve), which generally involve highly centralized networks with highly utilized maintenance facilities, to high-cost, high-performance configurations (toward the right side of the curve), which generally involve decentralized maintenance networks with high maintenance capacity and low utilization. Note that in graphical terms, the gray square falls below the curve. This implies that a management decision to implement a CONUS CIRF network could move cost/performance to any of the points along this curve, all of which are more cost-effective than the current system. One alternative is to move to a position represented by the gray circle (a network equal in cost to the current system but offering higher performance); another alternative is to implement a CONUS CIRF network represented by the gray triangle (a network equivalent in performance to the current system but with significantly lower annual operating costs).

2. Potential savings in manpower costs more than offset increased transport costs. CONUS CIRF network solutions tend to substitute relatively inexpensive transportation costs for relatively expensive maintenance manpower. The costs of these transshipments are more than offset by the reductions in maintenance manpower costs that occur in CIRF networks.

3. CONUS CIRF total pipeline requirements generally are not excessive. Pipeline asset requirements do not pose a problem in most implementation scenarios. New transport pipeline requirements are usually not large and are often offset by the reduction in awaiting maintenance (AWM) assets that results from centralized repair. Note that for centralized F-15 avionics maintenance, no reduction in AWM assets was identified, which means that the transport pipelines necessarily caused poorer performance under a CIRF network (although at reduced cost).

4. Many network designs are virtually equivalent in cost and performance. For each commodity and scenario that we studied, alternative CONUS CIRF network designs differing only slightly in cost and performance can be developed. In other words, the specific situation often permits a great deal of flexibility in the choice of network to be implemented.

5. Large user bases are naturally attractive CONUS CIRF locations. Bases that host large users of a commodity are prime candidates for a CONUS CIRF location (when all other variables are held constant) because of the resulting elimination of large transport pipelines. Most cost-effective CONUS CIRF networks result in the CIRF facilities being colocated at large user sites.

Specific Findings

In addition to our general findings about the characteristics of well-designed CONUS CIRF networks, we offer the following specific, commodity-oriented findings, which bear on CONUS CIRF implementation policies:

1. Spare engine pools are sufficient to support CONUS CIRF pipelines. Our analyses of TF34, F100, and F110 aircraft engines indicate that there are sufficient spare engine assets to adequately support the additional pipeline requirements needed to implement the CONUS CIRF concept. For the F100 and F110 engines, the reduced fleet sizes planned for the F-15 and F-16 imply that sufficient spare engines will be available.

2. CONUS engine retained tasks are not cost-effective. Some engine CIRF implementation schemes include a list of retained tasks, which are a subset of ILM actions that would still be accomplished at an operating location when it loses full ILM capability. We included a CONUS retained task option in our analyses, and our results indicate that such a policy is not cost-effective. That is, networks with retained task teams at aircraft operating locations cost more than networks with no retained tasks at equal levels of performance or, put another way, perform less well at equal levels of cost.

3. F-15 avionics ATE assets cannot support base-level bench check serviceable (BCS) screening. Of the F-15 avionics LRUs removed on the flightline, a significant proportion are determined to be serviceable upon testing in the ILM facility. These BCS assets are then simply returned to the spares inventory. Some proposals for CIRF implementation include having bases that lose full ILM capability retain the ATE assets needed to screen these LRUs out of the CIRF transport/repair channel. We conducted F-15 avionics LRU analyses with and without local screening for BCS conditions; we found that F-15 avionics BCS screening is not cost-effective. Further, for the units considered, the inventory of certain ATE assets is not sufficient to support this concept.[6]

4. F-15 avionics LRU spares pools are problematic. Many F-15 avionics LRUs are in critically short supply. The increased pipelines implied by CONUS CIRF implementation can be expected to increase the back-order situations for these assets. Note that no centralization-caused reduction in AWM assets was identified for these LRUs. In our

---

6 Note that the ATE asset with insufficient inventory—the AN/ALM-246 Tactical Electronic Warfare System (TEWS) Integrated Support System, or TISS—is currently undergoing a modernization program. The USAF decided against a new procurement because obsolescence issues made procurement prohibitively expensive.

detailed analyses, we attempted to estimate the impact of these critical items on F-15 support.

5. CONUS CIRF network performance is sensitive to assumed removal rates and repair times. Our analyses show that the ALQ-131 and ALQ-184 EW pods are good candidates for CONUS CIRF implementation. However, we also recognize that the results for these commodities suffer from a high level of uncertainty stemming from widely varying estimates of the wartime failure rates for these pods.[7] We therefore recommend additional study, drawing on data from current operations in Iraq and Afghanistan, to establish reliable wartime rates and factors for these assets.

In the case of aircraft engines, the standard repair times reported in the Propulsion Requirements System (PRS) or Logistics Composite Model (LCOM) data systems are often significantly shorter than the engine repair times reported in the Comprehensive Engine Management System (CEMS), even after subtracting the AWM and awaiting parts (AWP) times from CEMS. CONUS CIRF maintenance manpower requirements implied by the CEMS estimate are much higher than those derived from PRS- or LCOM-based repair time estimates. We therefore recommend that these repair time differences be fully reconciled as part of a CONUS CIRF implementation.

Organization of This Monograph

Chapter Two presents an overview of the research approach and methodology; Chapters Three, Four, and Five then discuss the scenario-based results for, respectively, aircraft engines, EW pods, and F-15 avionics and LANTIRN pods. Chapter Six offers an expanded discussion of our general findings and recommendations. A set of appendixes is included, providing details on the Q-METRIC model and the other analysis procedures developed for this project, all data used in the study and their sources, and the specific commodity analyses and results.

---

[7] This is a recognized difficulty for electronic countermeasure (ECM) pods (see Feinberg et al., 2002; also see Mills and Feinberg, 2001).

CHAPTER TWO

The Q-METRIC Modeling Approach

Despite the fact that CIRF operations have been analyzed in previous RAND studies, this analysis required a new modeling procedure. In this chapter, we show why we decided that the three most popular network analysis tools—(1) event-oriented Monte Carlo simulations, (2) network design tools based on mixed-integer linear programming (MILP), and (3) METRIC-like pipeline models—were inadequate for and inappropriate to the analytic task at hand. We then present an overview of the Q-METRIC analytic procedure we developed to perform the needed CONUS CIRF analysis.

CIRF Network Design as a Facility Location Problem

The design of a CIRF network can be thought of as a special case of the general analytic problem referred to as a *facility location problem*. This problem has been widely studied and reported on in the management science literature, and a number of commercial off-the-shelf (COTS) software packages that can model and "solve" very large-scale, real-world facility location problems have been developed.[1]

The commercial facility location problem is generally formulated as an attempt to design a set of geographically dispersed warehouses or distribution centers that will receive products from a set of manufac-

---

1 For an overview of the academic literature on facility location models, see Drezner, 1995. For an overview of commercial facility location software packages, see Ballou and Masters, 1999.

turing facilities (plants) and subsequently transship those products to a set of retail locations or customer regions (stores). The usual goal is to identify the distribution system design that minimizes annual system operating costs: the fixed and variable costs of the chosen warehouses, plus the annual freight costs associated with moving products from plants to warehouses and from warehouses to stores, plus the annual costs associated with holding the product inventory needed to support the network design.

The analysis usually minimizes these system costs subject to some form of customer service or performance constraint, often a minimum acceptable inventory availability and/or a maximum acceptable customer order delivery time. These network design tools are usually employed by large firms in the consumer packaged-goods segment of the economy. As such, the product flows that are modeled are very large in scale and generally involve the one-way flow of product in a supply chain or distribution channel. Consider, for example, the design of the distribution system a mass-market retailer such as Wal-Mart would use to flow products from manufacturers to its retail stores.

Monte Carlo Simulation Approaches to Logistics Network Design

Commercial logistics network design has sometimes been studied using large-scale, computer-based, discrete-event-oriented Monte Carlo simulations. The LCOM, which the USAF has used for decades to establish aircraft maintenance manpower authorizations, is an example of such a computer simulation (Fisher et al., 1968; also Dahlman, Kerchner, and Thaler, 2002). Such simulations can model the sequential activities experienced in a supply chain and can also deal very effectively with random and probabilistic events and activity times. In addition, these tools can provide very fine levels of detail about the expected costs and expected performance of the network being modeled, as well as estimates of variances to be expected in the system's costs and performance.

Simulation models for commercial logistics networks are generally constructed within the framework of a generic, off-the-shelf simulation modeling tool, and, as such, they can be fairly expensive and time-consuming to develop. Computer simulations must also "observe" network operations over an extended period to "average out" unusual events or circumstances so that their performance estimates for the system under study will be accurate. The contemporary computer can simulate and observe many years of a given network's performance in just a few seconds; but, in fact, even this is not fast enough to adequately address the CONUS CIRF network design problem. Processing time requirements severely limit the usefulness of simulation as a network design tool.

The basic issue is that a simulation analysis requires a specific network design as input. If this were a problem of choosing between two or three well-defined network alternatives, we could simply describe and simulate the alternative networks and then compare their costs and performance. However, when attempting to identify the best possible network, one must define, simulate, and estimate the performance of every possible network design. As the number of network "nodes" (number of physical locations) grows, the number of possible network designs to be analyzed increases very quickly.

As Table 2.1 shows, if we assume that there are ten aircraft operating locations and that a CIRF could be operated at any base, we must evaluate ten possible single-CIRF networks, 11,520 possible "two-CIRF" networks, and 262,440 possible "three-CIRF" networks. However, each one of these configurations is not a complete network design but, rather, a mere mapping of locations and support relationships. Maintenance capacity must be assigned to each repair facility for each mapping. Evaluating all of these possible alternatives via computer simulation simply takes too long. For this basic reason, Monte Carlo simulation is seldom used in designing large-scale commercial logistics networks and would not be a useful approach for the CONUS CIRF network design problem.

Table 2.1
Number of Possible Network Designs to Be Evaluated Given Ten Aircraft Operating Locations

Number of CIRFs Allowed	Number of Possible CIRF Configurations	Number of Possible Ways to Assign Operating Locations to CIRFs	Total Number of Possible Network Designs to Be Evaluated
1	10	1	10
2	45	256	11,520
3	120	2,187	262,440

MILP Approaches to Logistics Network Design

Most COTS software tools for logistics network design are now based on a large-scale, MILP formulation of the network design problem. These MILP formulations deal quite well with the combinatorially large number of possible networks that emerge in real-world problems having thousands of individual nodes or network locations. The MILP approach can implicitly enumerate and evaluate all of the possibilities and can identify an optimal or near-optimal network configuration, typically in just a few seconds, once the necessary input data have been assembled.

However, to develop this level of speed and "network search" capability, the MILP approach requires a much simpler and more aggregate representation of the logistics network than a simulation model requires. For example, simulation models will generate and observe thousands of individual shipments over time as they move from point to point in the logistics system, and will track and record each individual freight cost and transit time so as to eventually build an estimate of expected system performance. In contrast, MILP approaches simply create an aggregate point estimate by calculating the total annual flow across a link in the network. If we used an MILP approach, we would simply apply rates and factors rather than simulate and track each individual shipment over time. In this way, an MILP approach can quickly assess the total cost of any link or any node in any network. Combined with a sophisticated MILP "solver algorithm" (essentially a search engine), the MILP software can rapidly find the optimal network.

In the process, however, the MILP approach transforms the problem formulation from a dynamic, stochastic framework to a static, deterministic framework. As a result, the MILP treatment of network performance in terms of customer service measures is relatively crude. Commercial MILP network tools are designed for, and well adapted to, large-scale production/distribution scenarios with a high-volume, one-way flow of product, highly predictable item demand, and no significant queueing effects. These reasons made commercial MILP-based logistics network design tools inappropriate for the CONUS CIRF network design problem.

METRIC-Like Approaches to Logistics Network Design

As pointed out previously, the Dyna-METRIC model has been modified to include the operation of CIRFs within its maintenance network. However, even though the Dyna-METRIC model provides the capability to model CIRF activities, it is not an appropriate tool for resolving the questions that are to be addressed in this analysis. METRIC-like modeling tools consider transportation and maintenance activities as delay times in a component repair pipeline. The Dyna-METRIC model calculates the size of the expected component pipeline, compares it to the pool of spares assets available, and infers the item backorder posture or aircraft availability implied by the component item resupply pipeline status.

METRIC-like models require a pre-defined network of operating and maintenance locations as input to the analysis. More precisely, they require estimates of the transit times and maintenance times associated with the network locations. Further, the treatment of maintenance activities as simple pipeline time delays implies either that no component queueing takes place or that the expected queue time is somehow fixed. In any case, this treatment of maintenance prevents the tool from being able to estimate the capacity of a cost-effective maintenance facility for a given scenario. Our problem required a tool that could select an appropriate set of maintenance locations from a large set of potential sites, optimally size the maintenance capacity at each selected site, and optimally assign the operating locations to maintenance facilities. Faced with these requirements, the traditional METRIC-like models were inadequate.

Q-METRIC: A CIRF Network Design Algorithm

Since the three general modeling approaches—Monte Carlo simulations, MILP network optimization, and METRIC-like models (see discussion above)—were determined to be inadequate to support the design of a CONUS CIRF network, we developed a new analytic approach that would fulfill this need. We built a new pipeline modeling tool, which we call Q-METRIC, to perform the CONUS CIRF analyses detailed in this monograph.

In essence, the Q-METRIC approach captures the strengths of the MILP and METRIC approaches and eliminates many of their weaknesses, making it particularly well suited to the task of maintenance network design. Q-METRIC is a pipeline inventory model, similar to METRIC and Dyna-METRIC in that it calculates transport pipeline segments using simple unconstrained pipeline logic (the so-called Palm's theorem approach) to estimate spares asset requirements. However, for the repair segments of the component pipelines, a different set of analytic queueing models is used (the classic "*M*/*M*/*c*" queueing equations) so that the analytic tool can vary the size or capacity of a maintenance facility to adjust the number of assets expected to be in AWM status. In this way, the Q-METRIC model can "size" the maintenance operation much like an LCOM model can, but without the added computational burden of a Monte Carlo simulation.

We then embedded the Q-METRIC pipeline model in an iterative analysis process. The mean pipeline for each network segment was submitted to an MILP solver to establish plausible network designs to minimize network transportation and maintenance costs. These designs were then evaluated with Q-METRIC pipeline logic to optimally allocate available spares assets to pipelines and to assess total system performance in terms of supportability or end-item availability. The process was repeated across a broad range of spares allocations, budgets, and performance targets.

Figure 2.1 shows the modeling framework we used to evaluate design options for the CONUS CIRF network.[2] The three uppermost boxes show major categories of required input data for the model:

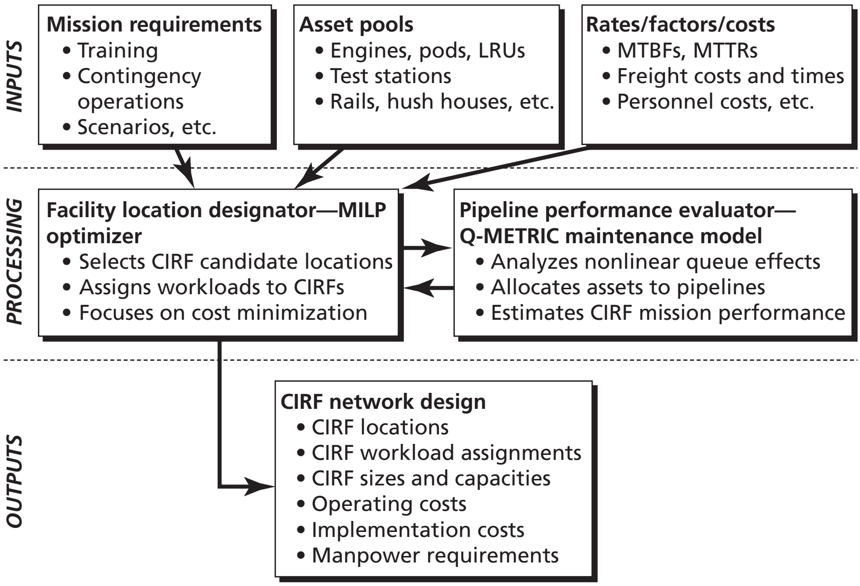
- *Mission requirements*: scenarios to be supported, peacetime-training requirements, and potential contingency operations requirements. These scenarios drive the CIRF demand requirements.
- *Asset pools*: commodities to be supported (engines, pods, and avionics LRUs) and repair equipment (test stations, engine rails, etc.).
- *Rates, factors, and costs*: commodity failure and repair rates (mean time between failures [MTBF], mean time to repair [MTTR], repair-equipment availability factors, transportation costs and times, personnel costs, facility operating and construction costs, etc.).

Our analytic framework combines an MILP with the Q-METRIC pipeline model, allowing the framework to evaluate a large number of potential network designs, including both the assignment of bases to ILM facilities and the sizing of ILM facilities. The two boxes in the middle of Figure 2.1 represent the mathematical models:

- *Facility location designator*: an MILP optimizer that designs a CIRF network by selecting CIRF locations from a candidate list, assigning workloads to the CIRFs, and determining CIRF manning and maintenance capacity.
- *Pipeline performance evaluator*: the Q-METRIC model developed to explicitly consider queueing (AWM) effects associated

[2] See Appendix A for a more detailed presentation of these mathematical models.

Figure 2.1
CONUS CIRF Modeling Framework



RAND *MG418-2.1*

with finite maintenance capability.[3] Q-METRIC analyzes the nonlinear queueing effects associated with stochastic failure and repair; it also allocates spares assets to pipelines in a near-optimal fashion.

These two mathematical models operate iteratively, the MILP determining a minimum-cost CIRF network, and Q-METRIC evaluating that network's performance. Initially, the MILP is solved with no constraint on system performance. The weapon system support (measured using mission capable rates or number of serviceable spares) of the output CIRF network is then evaluated using Q-METRIC. Next, a constraint requiring slightly improved system performance is added to the MILP, the new optimization model is solved, and Q-METRIC

---

3 This work is an extension of Sleptchenko, van der Heijden, and van Harten, 2002.

is used to evaluate the new solution. This iteration repeats until no further improvements can be made to system performance.

The box at the bottom of Figure 2.1 represents the model's output: a set of CIRF network designs, each containing a set of CIRF locations, base-to-CIRF workload assignments, CIRF sizes and capacities, operating costs, implementation costs, and manpower requirements.

Rather than simply producing one recommended network design, this process produces a set of "technically efficient" solutions to the network design problem. That is, for each set of input data, the Q-METRIC procedure develops and specifies a set of plausible network designs ranging from relatively inexpensive to relatively costly. As would be expected, total system cost and level of weapon system support go hand in hand: relatively low-cost networks generate relatively low levels of support, and relatively high-cost networks generate relatively high levels of support. However, each design is "efficient" in that no other network design costing that amount or less could provide as high a level of weapon system support. The decisionmaker is thus presented with a full description of the decision space and can make a reasoned judgment as to whether an incremental investment in network capability will produce a worthwhile increment in weapon system support.

Table 2.2 summarizes some of the most important differences between Q-METRIC and the traditional modeling approaches. In general terms, the Q-METRIC model improves on the traditional, spares-oriented pipeline models by explicitly incorporating maintenance capacity as a decision variable that is "traded off" in the analysis. Appendix A offers a more detailed, technical description of the full Q-METRIC procedure.

Table 2.2
A Comparison of Alternative CONUS CIRF Modeling Frameworks

Modeling Framework	Treatment of Maintenance Activity	Treatment of Maintenance Network	Focus of Analysis and Decisionmaking
Traditional pipeline models (METRIC-like models)	Maintenance modeled as expected delay time No dynamic AWM or queueing allowed No sizing of maintenance capacity possible	Fixed network of operating locations, CIRFs, and/or depots required as input to analysis	Primary focus on estimating expected support posture available from set of spares assets made available to network Some capability to optimally allocate spares across predetermined network locations
Monte Carlo simulations (LCOM-like models)	Maintenance modeled as number of servers Asset queueing (AWM) based on server availability Maintenance capacity input to analysis	Fixed network of operating locations, CIRFs, and/or depots required as input to analysis	Primary focus on estimating expected support posture available from set of logistics assets made available to network Some capability to allocate assets and capacity across predetermined network locations by trial and error
MILP network models (COTS models)	Activities and capacities modeled as average throughput rates Recoverable assets and queueing (AWM) not well represented	Operating locations (plants and stores) required as input Logistics facility (typically distribution center) networks are output from analysis	Primary focus on minimizing annual facility and transportation costs subject to relatively crude system performance constraints Network configurations chosen through optimization
Q-METRIC approach	Maintenance modeled as number of servers Asset queueing based on server availability Required maintenance capacity estimated	Operating locations required as input Maintenance/source of repair networks are output from analysis	Primary focus on establishing efficient frontier between operational performance and network maintenance and transportation costs Network designs involve optimal allocation of spares as well as optimal sizing and location of maintenance facilities

CHAPTER THREE

Results of Engine Analyses

Overview of Post-BRAC Bed-Downs and CIRF Assignments

The USAF has considerable prior experience with using CIRFs for jet engine repair; recent examples include both the overseas "Queen Bee" for engine repairs at Kadena AB (Korea) and the CONUS TF34 engine CIRF at Shaw AFB. The recommendations of the 2005 Defense Base Closure and Realignment (BRAC) Commission establish several new CONUS CIRF relationships for jet engines (2005 Defense Base Closure and Realignment Commission, 2005; referred to from here on as the "BRAC Report"). For example, Bradley ANG (Connecticut) loses its A-10 flying unit but becomes a TF34 CIRF, supporting Selfridge ANG (Michigan), Martin State ANG (Maryland), and Spangdahlem AB (Germany). Similarly, Seymour-Johnson AFB is designated to operate an F100 CIRF in support of Langley AFB. In doing our engine analyses for this study, we assumed implementation of these BRAC-designated CIRF relationships to be mandatory; we assume, however, that additional supported units may potentially be added to BRAC-designated CIRFs.

Our analyses focused on the engines supporting the USAF's primary fighter and attack aircraft fleets: the F110, F100, and TF34 engines.[1] There are two primary F110 models, the F110-100 and -129, and there are three primary F100 models, the F100-100, -220 (with

[1] We excluded the AFMC F110 and F100 aircraft at Hill and Edwards AFBs from our analysis because of these units' special engine testing mission.

A/E, B/F, and C/D series), and -229 (with A and B series). Appendix C provides further details on these engine fleets, along with a more detailed treatment of the analysis data and methodologies.

Some engine CIRF structure existed prior to the BRAC deliberations. For example, Barksdale Air Force Reserve Center provided a TF34 CIRF for New Orleans (retiring) and Whiteman Air Force Reserve Centers. Similarly, Eglin AFB (Florida) had its F110-100 JEIM performed at Dannelly Field ANG (Alabama), while Shaw AFB provided JEIM support for Eglin AFB F110-129 engines. The BRAC Report designated the closure of one pre-existing CIRF relationship: the TF34 CIRF at Shaw AFB (South Carolina) (which does not have an A-10 flying unit) that supported Pope AFB (North Carolina) (retiring), Eglin AFB, and Spangdahlem AB. We assumed that all other engine CIRF relationships that existed prior to the BRAC Report were not mandated and thus might be abolished, maintained, or expanded in our analysis.

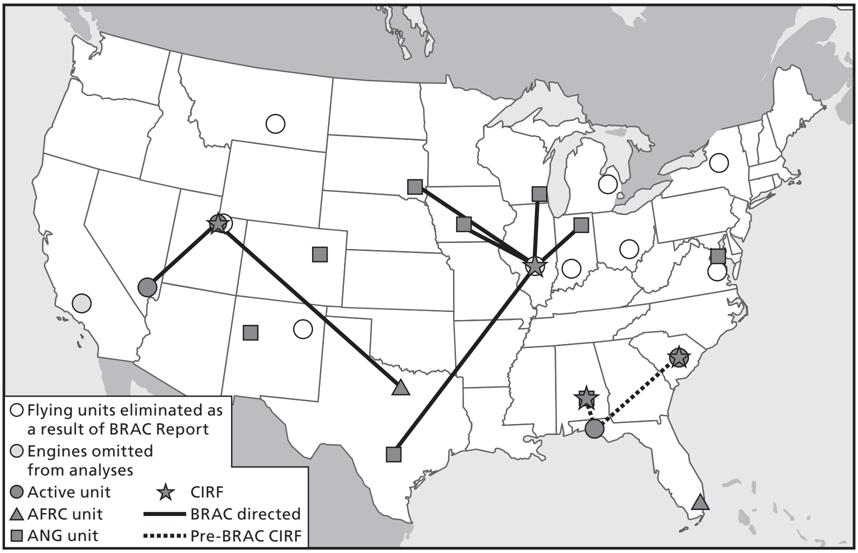
Figures 3.1, 3.2, and 3.3 present post-BRAC maps of the CONUS units using the F110,[2] F100, and TF34[3] engines, respectively. Detailed information concerning each unit's Primary Aircraft Authorization (PAA), by engine type, is presented in Appendix C. The uncolored circles in the figures represent flying units eliminated as a result of the BRAC Report. The light gray circle, representing Edwards AFB (California), which only appears in Figures 3.1 and 3.2, denotes that these AFMC aircraft were excluded from our analysis (as mentioned above, along with AFMC aircraft at Hill AFB [Utah]).

---

[2] All solid black lines in Figure 3.1 denote F110-100 engine assignments; the dashed line, which runs between Shaw and Eglin AFBs, denotes an F110-129 assignment.

[3] Note that the point representing Dover AFB (Delaware) in Figure 3.3 indicates the aerial port of debarkation for those engines arriving from Spangdahlem AB. Currently, these engines are flown via Air Mobility Command (AMC) into Dover AFB and shipped via air-ride truck from Dover to the CONUS CIRF. For the purposes of our study, we assumed that these engines emanated from Dover, ignoring the transit cost and engine pipeline between Germany and Delaware (since the Spangdahlem-Dover cost and pipeline would be constant for any CONUS CIRF receiving the engines from Dover).

Figure 3.1
Post-BRAC Network, F110 Engine



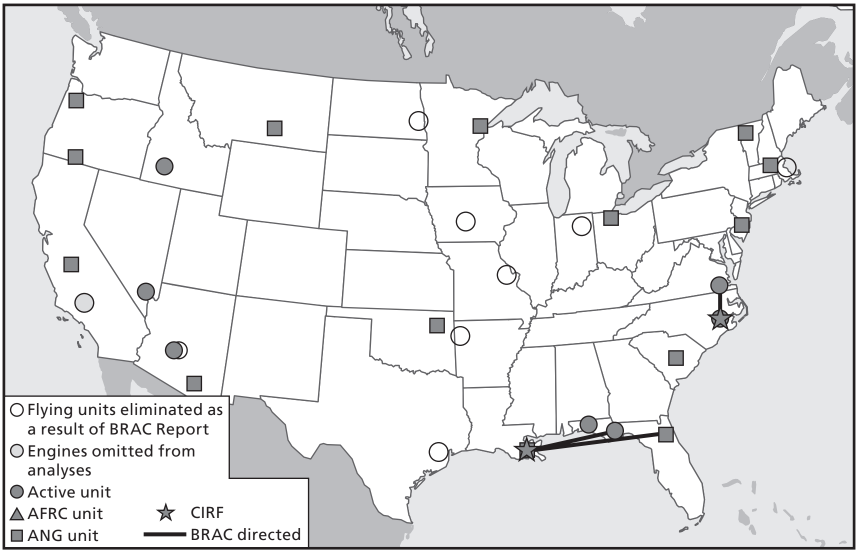
RAND *MG418-3.1*

JEIM Cost and Performance Measures

The performance metric used to evaluate JEIM CIRF networks is the expected number of serviceable spare engines available in the network, which is computed as the CONUS-wide authorized base stock level (BSL), minus the engines that are in work (INW), AWM, or AWP at a JEIM shop, minus the engines in transit (INT) between an operating location and a CIRF. The BSL is the authorized number of spare engines assigned to a base that is designed to support base operations. In effect, the worldwide total BSL is equal to the total number of USAF-possessed spare engines minus the expected number of engines in depot maintenance at any given time. This BSL total is then allocated across operating units.

Given that INW maintenance time would not be affected by the location at which ILM is performed and that AWP rates would

Figure 3.2
Post-BRAC Network, F100 Engine



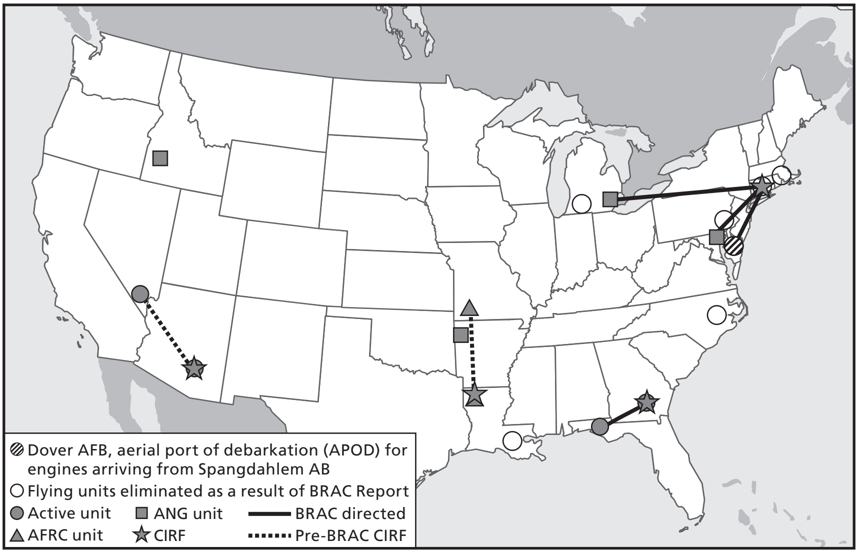
RAND *MG418-3.2*

remain constant in CONUS independent of ILM locations,[4] the expected number of engines INW and AWP depends only on the scenario's operating tempo and is independent of the CIRF network design. Therefore, the structure of the CIRF network can affect the expected serviceable spare level through only two counterbalancing effects:

1. changes in the number of engines expected to be INT, which would reduce the serviceable spares level as increasing workload is assigned to CIRFs
2. changes in the number of engines expected to be AWM, which would increase the serviceable spares level as increasing work-

[4] To account for the increased flying schedule associated with deployed operations, we assumed that deployed AWP rates increased proportionately with the increase in operating tempo between peacetime training and deployed operations.

Figure 3.3
Post-BRAC Network, TF34 Engine



RAND *MG418-3.3*

load is assigned to CIRFs because of load balancing and queueing effects.

The level of serviceable spare engines can be assessed against its goal, which is the WRE authorization. This authorization is computed for each combat-coded unit and is determined as the number of spare engines that the unit would be expected to consume during the first 30 days of a deployed combat operation.[5] The CONUS total serviceable spare engine level can be compared against the CONUS-wide WRE level to determine whether the network is providing sufficient support. We assumed common ownership of engines in a spare pool for this study—that is, any unit sending a failed engine to a CIRF would

---

5 For some engine types (e.g., F110-100), there are not enough spare engines to support the full WRE authorization. In such cases, the engine is classified as a "constrained engine" and is given a WRE goal deemed supportable.

receive the first available serviceable spare engine from the CIRF on a first-come, first-served basis.[6] While other prioritization schemes could be used to allocate available spares assets in a more strategic fashion, common ownership allows the overall system to achieve maximum overall performance.

The BRAC Report recommendations led to significantly reduced F-15 and F-16 fleet sizes, implying significantly reduced installed engine requirements for both the F110 and the F100. The CONUS-wide F110 spare engine pool and WRE allocation were not reduced in our analysis because the F110 demonstrated supportability problems prior to the fleet reductions—that is, the spare F110 engines associated with retiring aircraft were assumed to be retained by the post-BRAC fleet. The BRAC Report recommendations for the F100 engine were influenced by a concurrent plan to reduce the overall size of the F-15A/B/C/D fleet. This reduction involves retirement of the oldest aircraft and an upgrade in the performance of older-model aircraft that are to be retained. The long-term plan for the future fleet consists of only F-15C/D aircraft, all powered by F100-220A/E engines, which requires that upgrades and modifications be made to the current engine fleet.[7] Therefore, new BSL and WRE authorizations were computed to support the new F100 fleet. No new F100 engines were added to the pre-BRAC CONUS-wide fleet, although we did assume there would be a large number of engine upgrades.

The serviceable spares levels were measured against the system cost necessary to achieve them. Three components were considered in the system cost: transport cost, operating cost, and CIRF setup cost.

Transport costs were obtained from the CIRF CONOPS (Concept of Operations) Transportation Computation Chart (HQ USAF, 2004) based on an air-ride truck for each shipment with expedited service and dual drivers. The transit times between bases were obtained using the DoD Standard Transit Time—Truckload (U.S. Department of Defense [DoD], 2006); we added two extra days to each transit

---

6 This is the current policy for engines receiving off-base depot-level repair.

7 Personal communication, Tom Smith, Headquarters (HQ), Air Combat Command (ACC)/A4MP, December 16, 2005.

leg to allow for transit preparation time. We assumed that no engine pipeline or transit cost was encountered for engines receiving JEIM at their home-station bases. We also assumed a five-day, one-way transit time from any FOL to an in-theater OCONUS CIRF,[8] and a seven-day, one-way transit time between any FOL and any CONUS CIRF.[9] OCONUS transit cost was not considered.[10]

JEIM operating cost was defined as the associated personnel cost using a factor of $60,000 per man-year.[11] The Air Force PRS estimates were used to obtain MTBF data, which, combined with the scenario flying schedules (see Appendix B, Tables B.2 and B.3), determine the engine induction rates into the JEIM shops.[12] LCOM standards were used to determine the repair time per JEIM induction, with the repair task separated into its engine rail team and test cell components.[13] CONUS JEIM shops were assumed to operate 24 hours per day, five days per week, requiring three eight-hour shifts per line and a 40-hour

---

8 During the United States Air Forces, Europe (USAFE) CIRF test, average one-way transit times of 4.3 to 4.8 days were observed for F110 engines (see HQ USAF, 2004).

9 For the TF34 analysis, we deliberately used exceedingly conservative transit times of 15 days between OCONUS FOLs and the OCONUS CIRF and 21 days between OCONUS FOLs and CONUS CIRFs to demonstrate TF34 supportability within a CIRF framework.

10 We excluded OCONUS transport costs because we assumed them to be constant: the distribution of OCONUS JEIM work between OCONUS CIRFs and CONUS CIRFs is predetermined, FOL-OCONUS CIRF transport costs are not affected by the CONUS CIRF network design, and we assumed that transport cost from OCONUS would not vary greatly across different CONUS CIRF locations. We do, however, present estimates of potential OCONUS-CONUS transport costs later in this chapter (see No Retained Tasks OCONUS).

11 This value is based on an estimate of the typical rank structure of an aircraft maintenance unit and the Office of the Under Secretary of Defense (Comptroller), Fiscal Year 2006 Department of Defense Military Personnel Composite Standard Pay and Reimbursement Rates, undated.

12 Appendix B has a detailed discussion of the tasking scenarios developed for the study.

13 Engines are mounted onto structures called rails for repair. A rail team is the manpower required to perform the maintenance tasks associated with one engine mounted on one rail. A test cell consists of the manpower and equipment used to operate a fully assembled engine at full power for testing purposes.

workweek per maintainer.[14] The OCONUS CIRF was assumed to operate 24 hours per day, seven days per week, with two daily shifts of 12 hours each and a 60-hour workweek per maintainer. We performed an LCOM analysis to identify the potential for economies of scale in JEIM manpower, executing simulation runs for JEIM shops supporting a range of PAA, operating under both peacetime and deployed flying schedules. These analyses indicated that significant economies of scale were potentially achievable for JEIM shops: the JEIM manning for a 48 PAA unit would be considerably less than two times the manning for a 24 PAA unit flying at similar per-aircraft rates because of the increased utilization of personnel, reduced impact of minimum crew size effects, etc. Maintenance manpower was adjusted using man-hour availability factors, with additional management and support positions added to the requirement. No differentiation was made between different "types" of full-time manpower (e.g., active duty versus reserve component personnel). OCONUS CIRFs were assumed to be staffed entirely by personnel deploying from the CONUS CIRFs (i.e., the OCONUS CIRFs in this study did not use maintenance manpower from existing OCONUS CIRFs).

The only CIRF setup cost we considered was the cost required to obtain additional test cell equipment, which we computed as an annualized cost of $1 million per additional CIRF test cell.[15] We assumed that a CIRF would not operate under the command of the local operating unit, which would retain its own test cell (or "hush house") for testing installed engines, and thus that any base performing only its own home-station repair would continue to use its existing test cell

[14] For the TF34, we used a work schedule of two shifts, 16 hours per day, five days per week.

[15] We assumed that the T-9 test cells required at a CIRF could be obtained from the associated bases that had lost their JEIM. However, a building would have to be constructed to house the test cell, along with an augmentor/deflector repack kit and fire suppression, at a total cost of $3.9 million. These test cells require a major maintenance action every five years that costs between $500,000 and $1 million. Thus, the test cell setup and maintenance costs were discounted over a five-year interval at a real discount rate of 2.1 percent (Office of Management and Budget, 2004), resulting in an annualized cost of $1 million per additional CIRF test cell.

capabilities and not incur this test cell setup cost. We further assumed that test cell setup cost would not be incurred for any currently existing CIRF relationship (e.g., TF34 CIRF at Davis-Monthan AFB supporting Nellis AFB), but would be incurred if any additional supported units were assigned to an existing CIRF. OCONUS test cell costs were not considered in this analysis.

Retained Tasks and Dispatch Teams

For the F110 and F100 engines, any CONUS unit losing its current JEIM capability through assignment to a CIRF was authorized a retained task team. The motivation for using retained task teams is to allow failed engines requiring only a short maintenance action to be repaired on site, thereby avoiding the CIRF transportation costs and pipelines for these engines.[16] These CONUS retained task teams comprised five members, and one such team was required per "CIRFed" squadron (a squadron receiving ILM at an off-site CIRF). We assumed that CONUS retained task teams operated one shift of eight hours per day, five days per week, with a 40-hour workweek per maintainer, and that OCONUS FOLs sent their retained task failures to the OCONUS CIRF, which would be staffed entirely by personnel deploying from the CONUS CIRFs. The OCONUS FOLs' remaining, more labor-intensive failures were sent to a CONUS CIRF, in accordance with JEIM policy at the existing USAFE CIRF. OCONUS retained task teams required 12 manpower positions to staff a team for 24-hour by seven-day operations at the OCONUS CIRF, with a 60-hour workweek per maintainer. Note that the retained task concept does not apply to the TF34 engine.

We included an additional manpower authorization in this study to account for the fact that the active duty and reserve components use their JEIM personnel dissimilarly. JEIM personnel are used solely to perform ILM in active duty JEIM shops, whereas there is no such dis-

---

16 An analysis indicated, for example, that 45 percent of JEIM inductions for each F110 engine type are classified as retained tasks, with an average duration of 51 hours per JEIM retained task induction. The average duration of a non-retained-task JEIM induction was computed to be 278 hours for the F110-100.

tinction made for ILM in the reserve components. Maintenance personnel from reserve component JEIM shops are regularly dispatched to the flightline to assist with organizational-level maintenance tasks. As a result, any reserve component unit that loses its JEIM cannot be divested of its total JEIM manpower. A "dispatch team" must be retained to perform the additional, non-JEIM duties at the unit. Some precedent for this exists within the current AFRC TF34 CIRF arrangement. The AFRC units at New Orleans AFRC and Whiteman AFRC have their TF34 JEIM performed at a CIRF located at Barksdale AFRC. New Orleans AFRC and Whiteman AFRC each retain three full-time JEIM personnel to perform these additional tasks. Therefore, for any reserve component squadron that loses its JEIM capability in our analysis, a dispatch team of three or four personnel per squadron (depending on squadron size) is retained at the unit to perform the additional duties. These personnel are in addition to the retained task teams of five personnel per squadron assigned to any squadron (active duty or reserve component) losing its JEIM capability.

Cost-Performance Tradeoff Evaluated Against Deployment Scenario

The optimization model described in Chapter Two was used to identify the most cost-effective CIRF solutions to demonstrate the best system performance available for any level of expenditures. In this subsection, we demonstrate our analysis methodology using the F110 engine. A more detailed treatment of this methodology is presented for each engine type in Appendix C.

For the F110-100 and F110-129, the current CONUS BSL inventories are 132 and 28 spare engines, respectively, with total WRE authorizations of 85 and 20 engines, respectively. Data obtained from Oklahoma City Air Logistics Center (OC-ALC) indicate an average AWP of 5.0 percent and 6.6 percent of BSL spare engines (worldwide) for the F110-100 and F110-129, respectively.[17] Because of the higher tempo of the deployed flying schedule, the AWP fraction was increased proportionately to the deployment scenario's increased failure rate when compared against the purely peacetime flying schedule. Multiplying this increased AWP value by the CONUS-wide spare engine pools gives a mean expectation of 10.9 AWP F110-100 and 3.0 AWP F110-129 engines. We also assumed that the JEIM structure would have no effect on repair rates. Given the assumed repair rates, and accounting for the differences in CONUS and OCONUS work schedules and flying schedules, a total of 18.8 F110-100 and 4.4 F110-129 engines are expected to be INW across the CONUS and OCONUS CIRFs, independent of the CONUS JEIM network's design. Note that the OCONUS INT pipeline, containing a mean of 11.5 F110-100 and 1.9 F110-129 engines, is also independent of the CONUS JEIM structure. These considerations yield a maximum possible mean serviceable spare engine value of 91 F110-100 and 19 F110-129 engines (assuming zero engines AWM and zero engines in the CONUS INT pipeline).

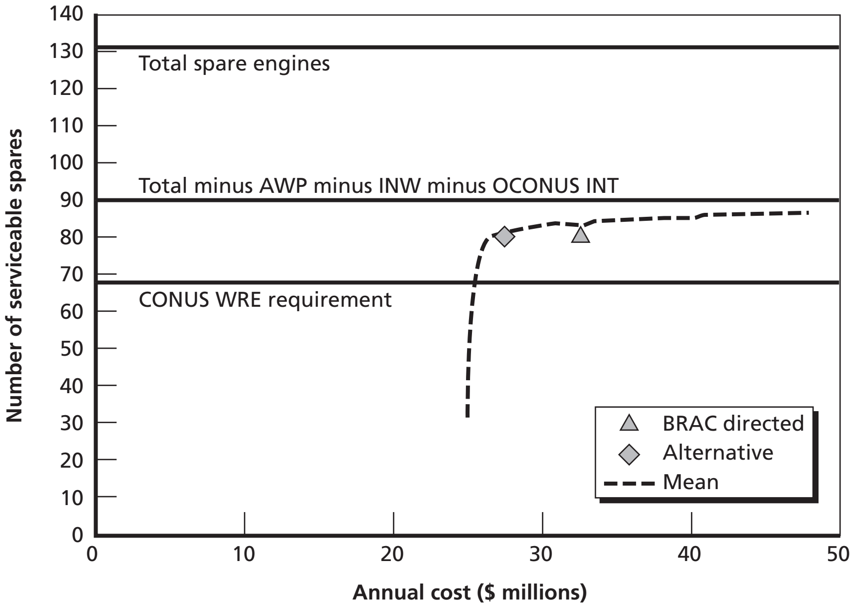
Figure 3.4 presents the results of the deployment scenario analysis for the F110-100 JEIM network, demonstrating the tradeoff between annual cost (transport cost, plus operating cost, plus annualized test cell setup cost) and number of serviceable spares available; Figure 3.5 presents a similar graph for the F110-129.[18] Note that the costs presented in each figure are those necessary to maintain the entire F110 engine pool and are not segregated by F110-100 or F110-129. The optimization model presented in Chapter Two was used to identify the points defining these curves, which demonstrate the best system performance (considering both engine types simultaneously) available for any level of expenditure. Note that each efficient frontier curve actually represents a very large number of potential solutions. For any point of

---

[17] C. R. McIntosh, CIRF F100F110GreenMetrics.ppt, January 2003–November 2004, OC-ALC/LR, 2005a; C. R. McIntosh, CIRF F100F110Metrics.ppt, January 2003–November 2004, OC-ALC/LR, 2005b; and C. R. McIntosh, F110 WW ENMCS%, January 2003–November 2004, OC-ALC/LR, 2005c.

[18] This general graph structure is used for analysis results throughout this monograph.

Figure 3.4
Deployment Scenario, F110-100 CIRF Network Options

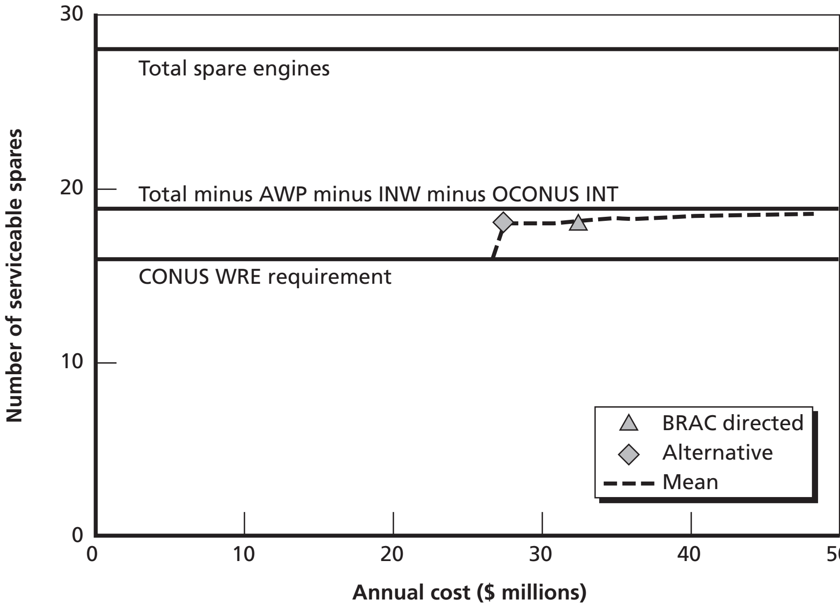


RAND *MG418-3.4*

interest along a curve (e.g., 80 serviceable F110-100 spares at a cost of $27 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the total combat-coded CONUS PAA, the serviceable spare levels can be kept above the residual WRE requirements of 68 F110-100 and 16 F110-129 engines (computed as 80 percent of the total CONUS WRE to reflect the fact that 20 percent of the combat-coded CONUS PAA is already deployed).

Within Figure 3.4, the blank area to the left of the curve indicates an unsupportable region: investments below this level (approximately $25 million annually in this case) do not provide sufficient maintenance capacity to repair the expected number of failed engines (in other words, maintenance utilization is greater than 1.0), and the number of serviceable engines (including installed engines) plunges

Figure 3.5
Deployment Scenario, F110-129 CIRF Network Options



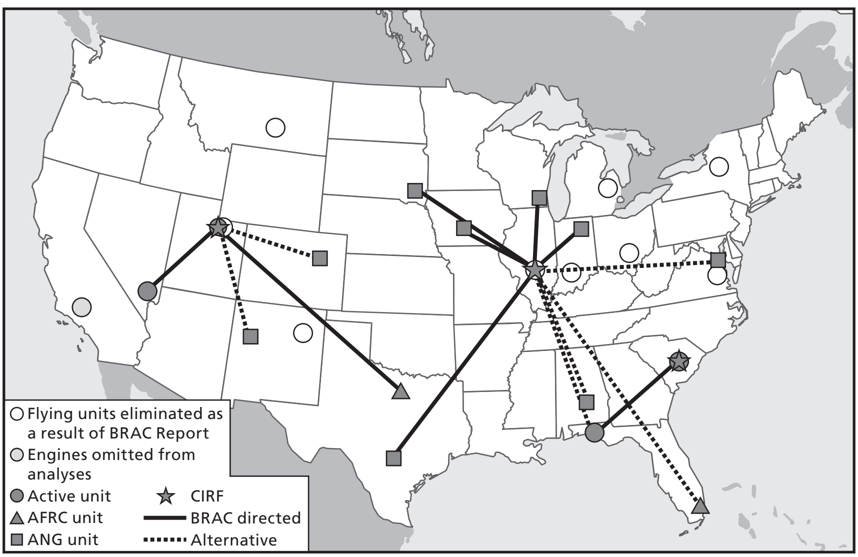
RAND *MG418-3.5*

to zero. The relatively steep slope at the left-most extreme of the curve reflects the dramatic reductions in AWM that can be achieved as maintenance utilization is reduced from values slightly less than 1.0 to more-stable values in the 80 percent range. Beyond this point, the curve is rather flat because of the relatively small effects of reductions in transport pipeline along with further reductions in utilization.

The historical cost and performance data that were collected do not reflect the post-BRAC force structure. Moreover, the worldwide engine availability data do not reflect the same deployed flying schedule, because their inclusion of support for OIF makes a direct comparison with these results somewhat difficult. To provide a more meaningful basis for comparison, we evaluated the post-BRAC F110 network presented in Figure 3.1 using the optimization model; we found that it produced 81 F110-100 and 18 F110-129 serviceable spare engines at a total cost of $32.6 million.

Rather than recommending any single network design as optimal, our analytic process identifies a set of alternative network designs lying along an efficient trade-space in which each identified network achieves the best possible weapon system support for its level of cost. For example, it is possible to identify a point on the efficient frontier curves of Figures 3.4 and 3.5 that achieves performance comparable to that of the post-BRAC network (81 F110-100 and 18 F110-129 serviceable spare engines) at a reduced cost of $27.4 million. The network configuration associated with this alternative solution is shown in Figure 3.6.[19] It is important to note that the curves appearing in Figures 3.4 and 3.5 are rather flat in the vicinity of this alternative solution, suggesting that one could identify other CONUS CIRF network designs differing

Figure 3.6
Alternative CIRF Network, F110 Engine



RAND *MG418-3.6*

[19] All lines in Figure 3.6 denote F110-100 engine assignments, with the exception of the solid line linking Eglin AFB to Shaw AFB, which denotes an F110-129 assignment that maintains a pre-BRAC CIRF not addressed in the BRAC Report.

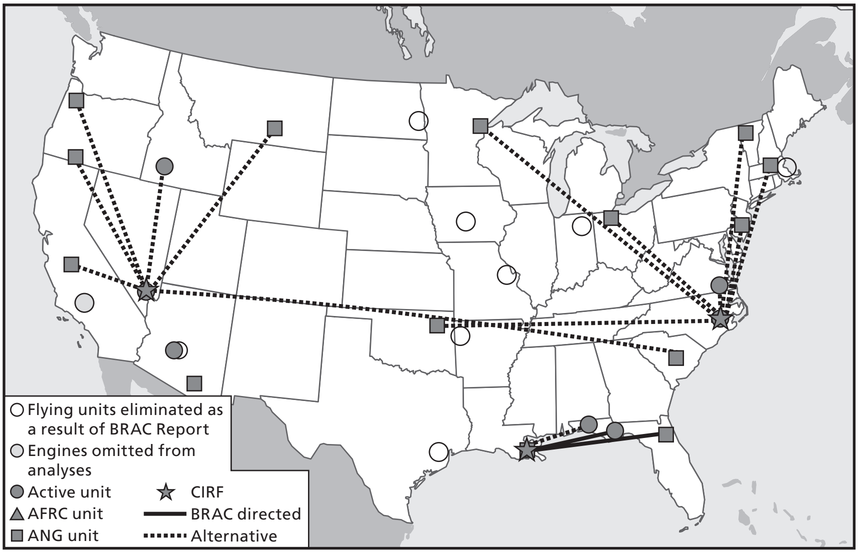
only slightly in performance from this alternative that may, based on considerations outside the scope of our analysis, be preferable. The alternative CIRF network has a total full-time manpower requirement of 414, with a total manning of 271 at the CONUS CIRFs,48 manpower positions at the OCONUS CIRF, 60 retained task team positions at the CIRFed units (excluding Eglin AFB, which had its F110 JEIM performed off site pre-BRAC), and a total of 35 dispatch team positions at the 11 CIRFed reserve component units. The post-BRAC network of Figure 3.1 has a total full-time manpower requirement of 504, with a total manning of 402 at the CONUS CIRFs/JEIM shops, 48 manpower positions at the OCONUS CIRF, 35 retained task team positions at the CIRFed units, and a total of 19 dispatch team positions at the six CIRFed reserve component units. Notice that the alternative solution requires 90 fewer full-time maintenance positions but increased transportation expenditures. The test cell setup cost is identical for the two solutions.

We also applied this analysis methodology to the F100 and TF34 engines (detailed in Appendix C), producing the alternative CIRF network designs shown in Figures 3.7 and 3.8.[20] Note that in Figure 3.7, two units, Luke AFB and Tucson ANG (Arizona), are not linked to any CIRF but instead maintain their home-station JEIM repair shops. These are both large bases—114 PAA at Luke AFB, and 62 PAA at Tucson ANG. If either of these bases were to assign its JEIM to an off-site CIRF, its demand would be large enough to produce a large transportation cost. However, because both bases achieve significant economy-of-scale benefits from their large size, the large transportation cost could not be offset by reductions in maintenance manpower via the CIRF.

---

[20] All lines in Figure 3.7 denote F100-220 engine assignments, with two exceptions: the dashed line linking McEntire ANG to Nellis AFB denotes an F100-229 assignment, and the dashed line linking Mountain Home AFB to Nellis AFB denotes an assignment for both F100-220 and F100-229 engines. Note also that the solid line in Figure 3.8 linking Nellis AFB to Davis-Monthan AFB denotes a pre-BRAC CIRF assignment that was maintained even though it was not addressed in the BRAC Report.

Figure 3.7
Alternative CIRF Network, F100 Engine



RAND *MG418-3.7*

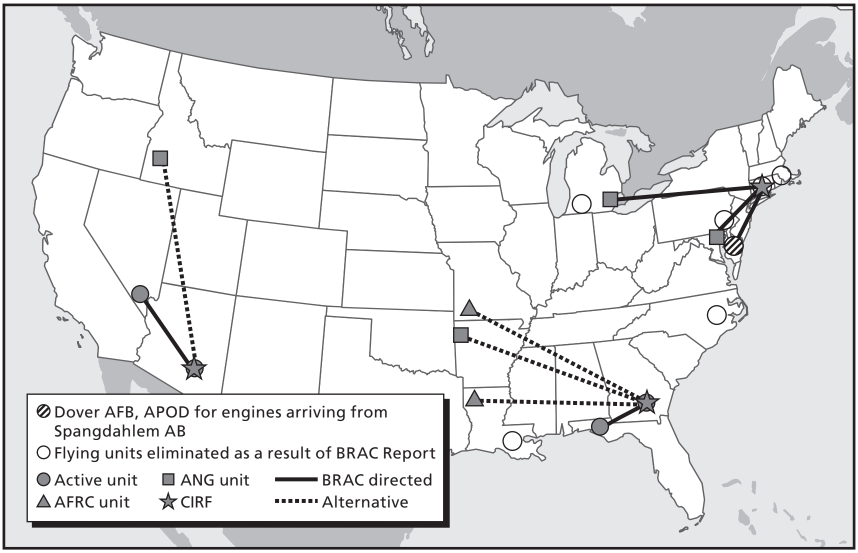
Alternative Maintenance Policies

Alternative maintenance policies were examined to determine their effects on CIRF cost and performance, both within CONUS and in a deployed OCONUS environment. For the F110 and F100 engines, we analyzed the results of eliminating retained tasks both at CONUS units and at OCONUS CIRFs. For the TF34 engine, a policy was examined wherein all OCONUS engine failures were evacuated to a CONUS CIRF.

No Retained Tasks CONUS

The retained task concept is currently used at OCONUS F110 CIRFs, but for a different reason than has been proposed for its use in CONUS. Compared with the manning requirement associated with all JEIM being performed at the OCONUS CIRF, fewer maintenance personnel need be deployed OCONUS when OCONUS CIRFs per-

Figure 3.8
Alternative CIRF Network, TF34 Engine



RAND *MG418-3.8*

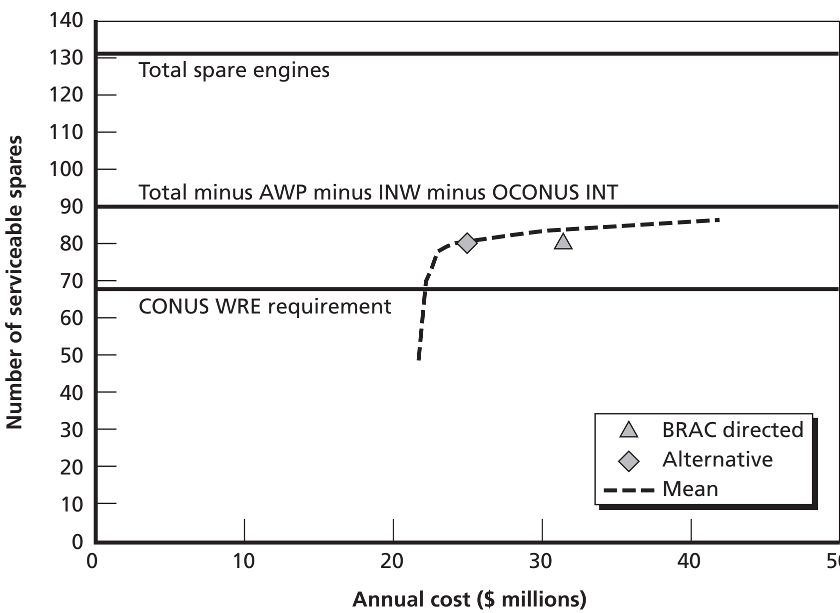
form only retained task maintenance actions for deployed aircraft. However, this policy adds to the number of engines in the OCONUS-CONUS pipeline, increasing the reliance on strategic airlift compared with the transport requirement when all deployed-aircraft JEIM is performed within the OCONUS theater.

These motivations do not apply to CONUS maintenance. Retained tasks could be used in CONUS to reduce CIRF transportation costs and engine pipelines at the expense of additional manpower. Because of this, we examined an alternative maintenance policy—one in which all CONUS units losing their JEIM shops retained no tasks, and thus no retained task teams—to determine the cost-effectiveness of retained tasks in CONUS. The dispatch teams assigned to reserve component units were not affected by this policy. Also, OCONUS maintenance was not affected by this policy: OCONUS FOLs still sent their retained task failures to the OCONUS CIRF, with the remaining, more labor-intensive failures sent to a CONUS CIRF.

Figures 3.9 and 3.10 present the efficient frontier curve resulting from our analysis using this alternative policy for the F110-100 and -129 engines, respectively. As with Figures 3.4 and 3.5, the costs shown are those necessary to maintain the entire F110 engine pool and are not segregated by F110-100 or -129. Note that the numbers of AWP and INW engines are unchanged under this policy, as is the OCONUS INT pipeline. Thus, the maximum possible mean serviceable spare value is, again, 91 F110-100 and 19 F110-129 engines (assuming zero engines AWM and zero engines in the CONUS INT pipeline).

Note that the mean serviceable spare levels for this policy remain above the residual CONUS WRE requirements for most expenditure levels. Comparison of the post-BRAC F110 and alternative F110 networks (Figures 3.1 and 3.6) reveals that they achieve similar

Figure 3.9
Policy of No Retained Tasks CONUS, F110-100 CIRF Network Options

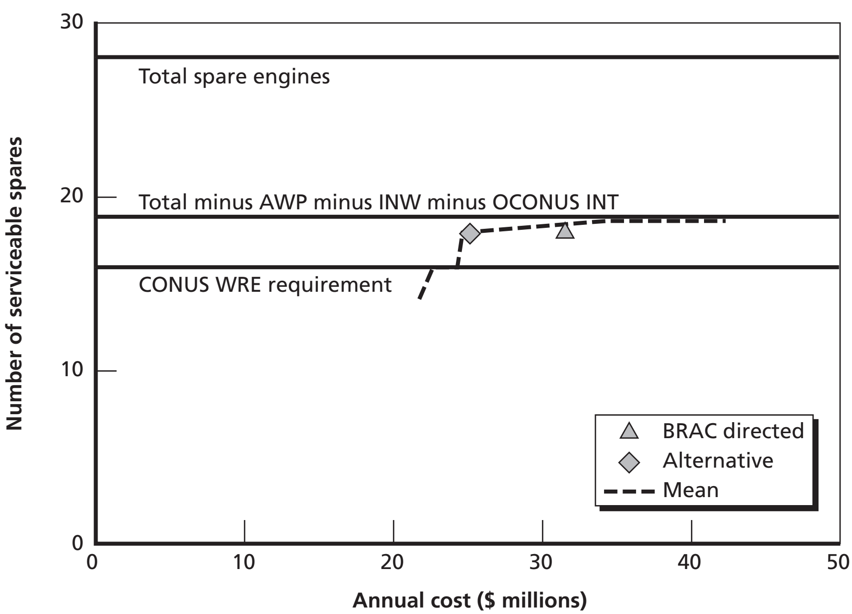


RAND *MG418-3.9*

performance (81 serviceable spare F110-100 and 18 serviceable spare F110-129 engines in both cases), with the alternative network achieving a 20 percent reduction in total cost ($25.0 million versus $31.5 million for the post-BRAC network). The alternative CIRF network has a total full-time manpower requirement of 368: a total manning of 285 at the CONUS CIRFs, 48 manpower positions at the OCONUS CIRF, and a total of 35 dispatch team positions at the 11 CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 483: a total manning of 416 at the CONUS CIRFs/JEIM shops, 48 manpower positions at the OCONUS CIRF, and a total of 19 dispatch team positions at the six CIRFed reserve component units.

Note that for both CIRF networks, the policy of no retained tasks CONUS achieves equal performance to the policy of retained tasks

Figure 3.10
Policy of No Retained Tasks CONUS, F110-129 CIRF Network Options



RAND *MG418-3.10*

CONUS. However, the first policy option achieves significant savings in both total cost ($25.0 million versus $27.4 million for the alternative network, $31.5 million versus $32.6 million for the post-BRAC network) and full-time manpower requirement (368 versus 414 for the alternative network, 483 versus 504 for the post-BRAC network). Therefore, the policy of no retained tasks CONUS is recommended for the F110 CIRF network. Similar results and conclusions were obtained for the F100 engine and are presented in Appendix C.

It should be noted that CONUS CIRFed units have a workload associated with shipping and receiving engines to and from the CIRF. While these tasks could reasonably be performed by the retained task teams, or the dispatch teams remaining at CIRFed reserve component units, they would constitute an added workload for the remaining personnel at CIRFed active component units without retained task teams. For the alternative F110, F100, and TF34 CIRF networks presented in this monograph, and the deployment scenario under consideration, this expected shipping/receiving workload consists of fewer than 30 engines per year at all but three AFBs: Langley (31 F100 per year), Mountain Home (82 F100 per year), and Tyndall (90 F100 per year). Assuming two man-days for shipping preparation at the base and one man-day for receipt of engines from the CIRF, the largest annual workloads in these cases equate to 93 man-days (~0.36 man-year) at Langley, 246 man-days (~0.95 man-year) at Mountain Home, and 270 man-days (~1.04 man-years) at Tyndall. Thus, these additional workloads are not expected to be very large at any individual unit.

No Retained Tasks OCONUS

Recall that the retained task policy is currently used at OCONUS CIRFs to reduce the deployment burden on maintenance personnel (compared with that associated with a policy of performing all OCONUS JEIM in theater) at the cost of an increased requirement for OCONUS-CONUS transport of engines. To investigate the impact of this policy, we tested the CIRF network presented in Figure 3.6 against the same deployment scenario, under the recommended policy of no retained tasks CONUS, concurrent with an alternative policy wherein the OCONUS CIRF performs JEIM for all OCONUS engine failures.

We found that this policy provided slightly better performance for the F110-100 engine (84 serviceable spares) and equal performance for the F110-129 engine (18 serviceable spares) at a reduced cost of $22.6 million. This policy has a total full-time manpower requirement of 327: a total manning of 175 at the CONUS CIRFs, 117 manpower positions at the OCONUS CIRF, and a total of 35 dispatch team positions at the 11 CIRFed reserve component units. Because OCONUS transportation costs are not included in this analysis, the cost differential between this policy and the retained tasks OCONUS solution ($22.6 million versus $25.0 million, respectively) is entirely due to the reduction in manpower positions from 368 to 327. Most of the personnel savings achieved with the policy of no retained tasks OCONUS can be attributed to differences in work schedules: CONUS CIRF personnel work a standard 40-hour workweek, whereas a 60-hour workweek is assumed for OCONUS CIRF personnel.

However, notice the deployment burden differences for the two policies. Recall that this scenario places 20 percent of the CONUS combat-coded fleet in a perpetually sustained deployment, necessitating a perpetually operating OCONUS CIRF. While an OCONUS CIRF's physical infrastructure can be thought of as permanent, individual maintenance personnel cannot be deployed OCONUS indefinitely—a rotational manpower pool is needed. Assume that dispatch team positions are interchangeable with CIRF positions. The policy of retained tasks OCONUS requires 48 out of a total of 368 manpower positions at an OCONUS CIRF, which is equal to all full-time JEIM personnel spending less than one-seventh of their time deployed OCONUS. The policy of no retained tasks OCONUS requires 117 manpower positions at an OCONUS CIRF out of a total of 327 positions, implying all full-time JEIM personnel spend more than one-third of their time deployed OCONUS. If the deployment burden is limited to a requirement that full-time JEIM personnel spend no more than one-fifth of their time deployed OCONUS, the no retained tasks OCONUS policy will require a total of 585 manpower positions—a significant increase over the 368 positions required for the retained tasks OCONUS policy—with a still-higher deployment burden: one-fifth versus one-seventh.

OCONUS maintenance policy also affects OCONUS-CONUS transportation requirements. This deployment scenario generates annual OCONUS failures of 344 F110-100 and 55 F110-129 engines. The policy of no retained tasks OCONUS would require no OCONUS-CONUS transport. However, every engine failure would require in-theater transport between the FOL and OCONUS CIRF. The policy of retained tasks OCONUS assumes that 45 percent of these failures would be retained at the OCONUS CIRF, generating an annual requirement of 189 F110-100 and 30 F110-129 shipments (each way) between the FOLs and CONUS CIRFs. Each engine in this OCONUS-CONUS pipeline places a requirement on strategic airlift. As discussed earlier, OCONUS transit cost was not modeled in this study; however, transit between FOLs and CONUS CIRFs is unlikely to be very costly. The cost to transport an F110-100 at the USAF AMC channel rate between Dover AFB and Al Udeid AB (for example) is $7,150 each way.[21] The retained tasks OCONUS policy would generate an associated annual OCONUS-CONUS transit cost of $3.1 million, which does not include OCONUS FOL–OCONUS CIRF transport. The key tradeoff occurs between these 438 OCONUS-CONUS shipments and the reduced JEIM manpower deployment burden achieved through the retained tasks OCONUS policy.

A similar examination was performed for the F100 engine (details are in Appendix C). We found that the F100 is a better candidate than the F110 for the policy of no retained tasks OCONUS because it exacts less of a deployment burden on JEIM personnel: each F100 JEIM manpower position would have to spend approximately one out of every 4.5 years deployed to an OCONUS CIRF, compared with one out of every 2.8 years for the F110.

Also note that if JEIM manpower is designed to support sustained deployment operations assuming shop operations of 24 hours per day, seven days per week, and a 60-hour workweek (as assumed at OCONUS CIRFs), little additional capacity will be available to support more-stressing, surged operations. Note that the policy of retained

---

[21] F110-GE-100 dry weight is 3,920 lb (General Electric, 2007); AMC channel rate between Dover AFB and Al Udeid is $1.824 per lb each way (U.S. Government, 2005).

tasks OCONUS is able to perpetually sustain deployment operations using a workweek of three shifts by 40 hours at the CONUS CIRFs. This policy could provide additional support during surged operations through the use of CONUS manning in a 60-hour workweek environment, potentially extending JEIM's capability to support surged operations. Such considerations may also impact WRE requirement computations.

All Repair in CONUS

Despite the fact that, as discussed earlier, retained tasks are not a consideration for the TF34 engine, deployment burden considerations also influenced the TF34 analysis. The first maintenance policy we examined for the TF34 was an OCONUS CIRF policy in which all OCONUS engine failures were maintained at an in-theater OCONUS CIRF. Under this policy, the CONUS CIRF network presented in Figure 3.8 achieved 91 serviceable spare engines at a total cost of $18.5 million, with a total full-time manpower requirement of 251: a total manning of 180 at the CONUS CIRFs, 50 manpower positions at the OCONUS CIRF, and a total of 21 dispatch team positions at the six CIRFed reserve component units. Note that the mean serviceable spare level for this policy greatly exceeds the residual CONUS WRE requirement of 40 TF34 engines.

However, this manpower requirement is potentially misleading. The relative size of the rotational pool depends on the deployment burden deemed acceptable for maintenance manpower. If the alternative network's total CONUS manning of 201 personnel (including dispatch team members) is used to support its OCONUS manpower requirement of 50 positions, all full-time JEIM personnel will have to spend one-fifth of their time deployed OCONUS. This is consistent with the general AEF construct, wherein full-time USAF personnel are eligible to spend one-fifth of their time deployed, implying that five full-time manpower positions are required systemwide to support one perpetually deployed position.

We have assumed that dispatch team positions are interchangeable with CIRF positions. If this assumption is not valid, the deployment burden on JEIM personnel will be greater. The total manpower requirement would be 271 full-time positions for the alternative network, with 250 CIRF positions required to support a perpetual deployment of 50 positions, and 21 dispatch team positions required. At any point in time, 221 of these full-time CIRF and dispatch team positions would be within CONUS, which is greater than the 201 manpower positions required for the residual CONUS fleet's workload.

An alternative to using OCONUS CIRFs would be to retrograde all OCONUS engines requiring JEIM from the FOLs to the CONUS CIRFs. Such a policy imposes a burden on the transportation system but eliminates the rotational burden on manpower. Note that the use of OCONUS CIRFs also depends heavily on transportation, both for moving engines between FOLs and the OCONUS CIRF and for rotating JEIM personnel between the CONUS and OCONUS CIRFs. We tested this alternative maintenance policy against the same scenario. Instead of our 15-day, one-way transit between OCONUS FOLs and the OCONUS CIRF, we imposed a 21-day, one-way transit from any FOL to any CONUS CIRF. Also, we assumed that the CONUS CIRF would maintain its work schedule of 16 hours per day, five days per week, rather than the OCONUS schedule of 24 hours per day, seven days per week.

We analyzed the CONUS CIRF network presented in Figure 3.8 under the policy of all repair in CONUS and found that performance was similar (92 serviceable spare engines) to that for the OCONUS CIRF policy at comparable cost ($19.1 million for the alternative network). The alternative all-CONUS repair CIRF network had a total full-time manpower requirement of 261: total manning of 240 at the CONUS CIRFs and a total of 21 dispatch team positions at the six CIRFed reserve component units. As with the other engine analyses, OCONUS transit cost was not modeled; however, transit between FOLs and CONUS CIRFs is unlikely to be very costly. For example, the cost to transport a TF34 at the AMC channel rate between Dover AFB and Al Udeid AB is $3,419 each way.[22] This deployment scenario has an annual requirement of 82 engine shipments (each way) between

[22] TF34-GE-100 dry weight is 1,440 lb (General Electric, 2007); AMC channel rate between Dover AFB and Al Udeid AB is $2.374 per lb each way (U.S. Government, 2005).

the FOLs and CONUS CIRFs, producing an associated annual transit cost of $561,000.

The most significant distinction between the two policies is the difference in deployment burden: the OCONUS CIRF policy requires all full-time JEIM manpower to spend one-fifth time deployed, whereas the policy of all repair in CONUS has no deployment requirement for JEIM manpower but incurs an additional requirement for strategic lift between OCONUS FOLs and CONUS CIRFs.

Part-Time Manning Implications

We used the MRC tasking scenario, whose development is described in Appendix B, to determine the needed part-time manning requirement for the reserve component for each engine. Because this scenario is not assumed to be the perpetual condition for USAF forces, we paid less attention to deployment burden effects and put the priority on minimizing strategic airlift, which led to a policy that assumed deployed aircraft would receive all JEIM from their unique in-theater OCONUS CIRF. We assumed that CONUS residual aircraft would receive JEIM from a CONUS CIRF; we also assumed the recommended policy of no retained tasks in CONUS for the CONUS residual F110 and F100 aircraft. For the F110 engine, the CONUS manning requirement was computed to be 57 positions, and each of the two OCONUS CIRFs required 241 manpower positions, giving a total MRC manning requirement of 539. The difference between these 539 positions and the manpower computed previously to support the 20 percent deployment scenario defines the part-time manning requirement. Similar computations were performed for the TF34 and F100 engines.

Output Tables

The efficient frontier curves presented in Figures 3.4 and 3.5 and Figures 3.9 and 3.10 represent a very large number of potential solutions. Each point lying on these curves is associated with a specific CIRF network design. Table 3.1 summarizes the maintenance, transportation, and equipment (annualized test cell setup) costs, as well as the system performance and manpower requirements associated with the 20 percent deployment scenario for the F110 post-BRAC and alternative CIRF networks for all policies considered. Note that the part-time manning requirement to support a large-scale MRC deployment has been included in this table and costed at a rate of $15,000 per part-time drill position. Tables 3.2 and 3.3 present similar information for the F100 and TF34 engines.

It should be noted that the total CONUS F110 WRE requirements are 85 F110-100s and 20 F110-129s, although the F110-100 is classified as a constrained engine with a WRE computation of 111 engines. Because the tested scenario assumes that 20 percent of the combat-coded aircraft are deployed, it is assumed the WRE requirements also can be reduced by 20 percent, giving residual WRE requirements of 68 F110-100s and 16 F110-129s (89 F110-100s, if the WRE computation is considered). Similarly, the residual CONUS WRE requirements are 69 F100-220, nine F100-229, and 40 TF34 engines. Note that the alternative CIRF solutions (along with other solutions identified on the curves) exceed the required performance for all policies considered in support of perpetually sustained deployment operations. These results indicate that a small number of JEIM CIRFs can simultaneously provide a cost-effective solution and acceptable performance.

Impact of Engine Repair Times

We examined multiple data sources for engine repair times and found widely varying estimates of this key data input. Data standards, such as the repair times inherent in the LCOM simulation, are used in Air Force maintenance planning. Repair time observations, compiled in the CEMS database, record the observed maintenance time for individual engine inductions into the JEIM shop. Table 3.4 presents both the standard and the observed mean engine repair time per JEIM induction for each engine of interest. Note that in four out of five instances, the observed mean time exceeds the repair time standard by more than 50 percent. For both members of the F100 engine family, the observed mean time is more than double the data standard.

Table 3.1
Cost and Performance for F110 CIRF Networks

	BRAC Directed		Alternative		
Retained tasks					
CONUS	Yes	No	Yes	No	No
OCONUS	Yes	Yes	Yes	Yes	No
Maintenance locations (CONUS/OCONUS)	8/1	8/1	3/1	3/1	3/1
Serviceable spares					
F110-100	81	81	81	81	84
F110-129	18	18	18	18	18
Costs ($M)					
Payroll	30.8	29.8	26.7	24.6	22.8
Transportation	0.3	0.5	0.5	0.9	0.9
Test cell	2.1	2.1	2.1	2.1	2.1
Total	33.2	32.4	29.3	27.6	25.8
Manning					
CONUS full-time					
JEIM/CIRF	402	416	271	285	175
Retained task/ dispatch team	54	19	95	35	35
CONUS part-time	35	56	125	171	212
OCONUS full-time	48	48	48	48	117
Mean transport pipeline					
CONUS, F110-100	2.4	4.3	4.3	7.8	7.8
CONUS, F110-129	0.2	0.2	0.2	0.2	0.2
OCONUS, F110-100	11.5	11.5	11.5	11.5	9.4
OCONUS, F110-129	1.9	1.9	1.9	1.9	1.5

Table 3.2
Cost and Performance for F100 CIRF Networks

	BRAC Directed		Alternative		
Retained tasks					
CONUS	Yes	No	Yes	No	No
OCONUS	Yes	Yes	Yes	Yes	No
Maintenance locations (CONUS/OCONUS)	18/1	18/1	5/1	5/1	5/1
Serviceable spares					
F100-220	92	90	82	82	85
F100-229	18	18	15	16	16
Costs ($M)					
Payroll	50.8	49.4	41.6	37.7	37.5
Transportation	0.1	0.2	0.6	1.7	1.7
Test cell	2.1	2.1	3.1	5.2	5.2
Total	53.0	51.7	45.4	44.6	44.5
Manning					
CONUS full-time					
JEIM/CIRF	737	749	403	481	419
Retained task/ dispatch team	38	3	203	38	38
CONUS part-time	0	0	63	150	154
OCONUS full-time	72	72	72	72	130
Mean transport pipeline					
CONUS, F100-220	1.8	5.2	5.3	15.6	15.6
CONUS, F100-229	0.0	0.0	1.2	2.7	2.7
OCONUS, F100-220	14.7	14.7	14.7	14.7	13.0
OCONUS, F100-229	2.2	2.2	2.2	2.2	1.8

Table 3.3
Cost and Performance for TF34 CIRF Networks

	With OCONUS CIRFs		All Repair in CONUS	
	BRAC Directed	**Alternative**	**BRAC Directed**	**Alternative**
Maintenance locations (CONUS/OCONUS)	6/1	3/1	6/0	3/0
Serviceable spares	91	91	92	92
Costs ($M)				
Payroll	17.4	15.9	17.9	16.4
Transportation	0.1	0.3	0.1	0.3
Test cell	2.1	3.1	2.1	3.1
Total	19.6	19.3	20.1	19.8
Manning				
CONUS full-time				
JEIM/CIRF	224	180	284	240
Dispatch team	11	21	11	21
CONUS part-time	23	57	13	47
OCONUS full-time	50	50	0	0
Mean transport pipeline				
CONUS	1.7	2.7	1.7	2.7
OCONUS	6.8	6.8	9.5	9.5

As discussed in the data modeling section of Appendix B, we used data standards in our analysis of JEIM CIRF options. To demonstrate the impact of engine repair times on the analysis, we examined the alternative CIRF networks for each engine using observed repair time data. The policy of all repair CONUS was assumed for the TF34; the policy of no retained tasks CONUS and retained tasks OCONUS was assumed for both the F110 and F100. Table 3.5 presents the results of this comparison. Note that part-time manning is not included.

Table 3.4
Standard and Observed Mean Repair Time per JEIM Induction for Engines of Interest

Engine	Data Standard (hours)	Repair Time Observations (hours)
TF34	200	385
F110-100	176	279
F110-129	247	188
F100-220	86	201
F100-229	79	197

Table 3.5
Manning and Performance Comparison for Standard Versus Observed Engine Repair Times

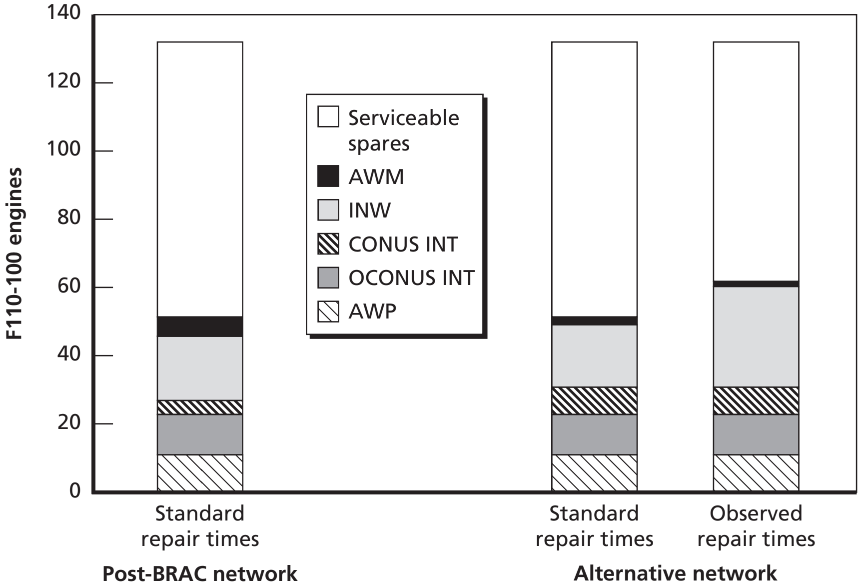
	TF34		F110		F100	
	Data Standard	Repair Time Obs.	Data Standard	Repair Time Obs.	Data Standard	Repair Time Obs.
Serviceable spares	92	81	-100: 81 -129: 18	-100: 70 -129: 19	-220: 82 -229: 16	-220: 54 -229: 12
Full-time manning						
CONUS						
JEIM/CIRF	240	456	285	379	481	981
Dispatch team	21	21	35	35	38	38
OCONUS	0	0	48	48	72	72

Observe that for each engine, the manning requirement computed using repair time observations is significantly larger than that associated with data standards, with manning increases greater than 80 percent for the TF34 and F100 engines. Note that for four out of five engines, repair time observations produced a smaller serviceable spare level than did the data standards. The only exception was the F110-129, which is the only engine for which data standard engine repair time is greater than the observed mean value. If all of these engine analyses were performed using the repair time observations, it is possible that different CIRF networks would be recommended. The part-time manning requirement would also increase if repair time observation data were used in the analyses.

Consider that in Table 3.5 each engine has a single transport pipeline as well as a unique AWP rate. The differences in performance for data standards versus observations stem from differences in repair times, which impact the mean number of engines INW, and differences in AWM. Longer repair times represent increases in INW engines, which reduce the number of available serviceable spare engines. The effect of AWM also explains how the more-consolidated alternative networks achieve performance similar to that of the post-BRAC networks despite using fewer maintenance personnel and including greater transport pipelines. The more-consolidated networks, with a smaller number of very large maintenance facilities, are better suited to handling the random fluctuations that occur in engine demand. Recall the assumption that the JEIM structure should have no effect on either INW engines (assuming a constant repair time) or AWP rates. The larger size of the consolidated maintenance facilities means that the number of AWM engines can be greatly reduced compared with that of the less-consolidated, post-BRAC network because of the effects of queueing at the JEIM. Figure 3.11 presents an accounting of the expected number of F110-100 engines in various states for the post-BRAC F110 network using data standards and for the alternative F110 CIRF network using both data standards and repair time observations.

When standard repair times are used, the alternative network is able to compensate for its increased CONUS transit pipeline when compared to the post-BRAC network via reductions in AWM engines, even while requiring less manpower than the post-BRAC network. When the alternative CIRF network is held constant, note that the large increase in INW engines associated with observed repair times prevents its serviceable spares level from achieving the performance possible with the standard repair times.

Figure 3.11
Engine Accounting for F110-100



RAND *MG418-3.11*

CHAPTER FOUR

Electronic Warfare Pods

The ALQ-184 and ALQ-131 are self-protect ECM pods that are used on both A-10/OA-10 and F-16 aircraft. Because these avionics pods are currently supported using a three-level maintenance concept, they were included as candidate CIRF commodities within this analysis of ILM for USAF fighter and attack aircraft fleets. The BRAC Report designates one ALQ-184 CIRF relationship. Shaw AFB will operate an ALQ-184 CIRF supporting Moody AFB. The report does not, however, designate any ALQ-131 CIRF relationships. We have assumed for our ECM pod analysis that the BRAC-directed ALQ-184 CIRF relationship is fixed, although we assume that additional supported units may potentially be added to the BRAC-designated CIRF. No CONUS CIRF structure existed for either the ALQ-184 or the ALQ-131 prior to the BRAC deliberations.

Currently, there are two versions of the ALQ-184 pod: the ALQ-184-Short and ALQ-184-Long. Because all ALQ-184-Short pods are being upgraded to ALQ-184-Long, we considered all ALQ-184 pods to be the Long version.

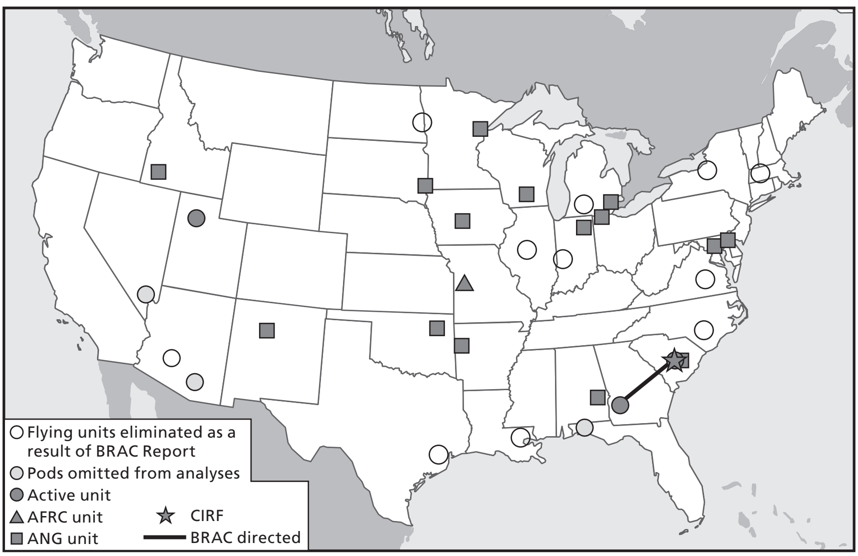
Prior to BRAC, the ALQ-131 pods assigned to AFRC units had received an upgrade modification: all 49 pods were equipped with a MIL-STD-1553 data bus card. No other pods had received this upgrade pre-BRAC, although there are plans to perform this upgrade on the entire fleet of ALQ-131s.[1] Because the AFRC paid for this card

1 All ALQ-131 pods have been funded to be equipped with this upgrade from fiscal year (FY) 2008 through FY 2009 (personal communication, Daniel Graham, ACC/A3IE, via email dated February 14, 2007).

upgrade, it was assumed that the 49 upgraded pods will be assigned to AFRC units post-BRAC.[2] Note that this upgrade impacts neither the pod's failure rate nor its repair. However, unlike jet engines, for which this study assumed common ownership in a spares pool, the upgraded pods need to be tracked separately to ensure that they return from the CIRF to an owning AFRC unit. All other pods assume common ownership in a spares pool.

Figures 4.1 and 4.2 present post-BRAC maps of the CONUS units using the ALQ-184 and ALQ-131 pods, respectively.[3] Detailed information concerning each unit's PAA, by pod type, is presented in Appendix D. The uncolored circles in the figures represent pod-equipped units that will be eliminated as a result of the BRAC Report.

Figure 4.1
Post-BRAC Network, ALQ-184



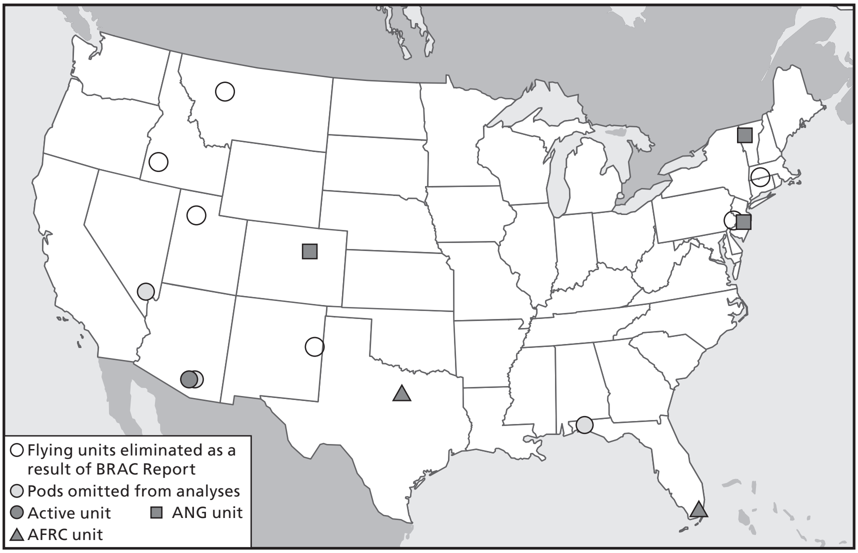
RAND *MG418-4.1*

---

2 Personal communication, Daniel Graham, ACC/A3IE, via email, September 23, 2005.

3 The Nellis AFB, Eglin AFB, and Tucson ANG pods were omitted from these analyses. These units, which support pod testing requirements, are shown as light gray circles in Figures 4.1 and 4.2.

Figure 4.2
Post-BRAC Network, ALQ-131



RAND *MG418-4.2*

The ALQ-184 and ALQ-131 analyses were performed separately for two reasons: no units under consideration operate both types of pods, and each type of pod requires its own electronic test stand—the AN/ALM233-D and AN/ALM-256, respectively—to perform pod ILM. Thus, from a cost-benefit standpoint, there is no benefit to performing ILM for both pods at any single site.

It was assumed that all pre-BRAC ALQ-184 and ALQ-131 units that retained either A-10/OA-10 or F-16 aircraft following implementation of the BRAC Report recommendations would also retain an ECM pod assignment. Moody AFB was assumed to be the only new ALQ-184 unit. No new ALQ-131 units were considered. All post-BRAC ALQ-184 operating locations were considered for potential ALQ-184 CIRF sites. Similarly, all post-BRAC ALQ-131 operating locations were considered for potential ALQ-131 CIRF sites. No other potential CIRF locations were considered in these analyses.

EW Pod Requirements Post-BRAC

Following implementation of the BRAC Report recommendations, the number of CONUS PAA operating the ALQ-184 and -131 pods will be reduced. Table 4.1 shows the total PAA for CONUS units equipped with EW pods both pre- and post-BRAC, along with the pre-BRAC pod inventories (excluding Eglin AFB, Nellis AFB, and Tucson ANG, for reasons noted earlier). Note that all ALQ-184 and -131 pods in this analysis are assigned to combat-coded squadrons.[4] Because the total number of CONUS PAA supported by these pods decreases significantly, we performed an analysis to determine if a post-BRAC requirement exists for all 643 ALQ-184 and 265 ALQ-131 pods. Details of this analysis appear in Appendix D.

The deployment-based pod requirement must satisfy the following objective: Every deployed sortie must have a fully mission capable (FMC) ECM pod. Flying units need to deploy with spare pods beyond their PAA level to compensate for failed pods. Additional spare pods are also needed at the ILM facility supporting the deployed unit to compensate for AWP shortages.

Determining a failure rate for ECM pods is somewhat difficult because of limitations on pod use during peacetime training missions. Their interference with civilian communications is what prevents

Table 4.1
EW Pods—Inventories and Equipped PAA

PAA	Pre-BRAC CONUS Pods	Equipped CONUS PAA: Pre-BRAC	Equipped CONUS PAA: Post-BRAC
ALQ-184	643	564	498
ALQ-131	265	237	126

[4] The BRAC Report realigns the squadron of A-10/OA-10 aircraft at Eielson AFB to CONUS units but does not realign the F-16 squadron at Eielson AFB. Pre-BRAC, 40 ALQ-184 pods were assigned to Eielson. Because Eielson loses one-half of its fighter aircraft due to BRAC Report recommendations, we assumed that one-half of Eielson's ALQ-184 pods would be reassigned, resulting in a total of 643 pods to potentially be assigned to these CONUS units.

ECM pods from being fully activated during most training missions. Furthermore, it is difficult to determine whether a pod is working correctly in a non-threat environment. Although a small number of pod failures are diagnosed during training missions, scheduled maintenance accounts for the majority of the ECM pod workload during peacetime. ALQ-184-Long pods have a periodic maintenance interval (PMI) of 90 calendar days, while ALQ-131 pods have a PMI of 180 calendar days. A data modeling analysis was performed (see Appendix B) that indicated a mean pod failure rate of 0.0196 failures per ALQ-184 operating hour and 0.0098 failures per ALQ-131 operating hour. Note that the majority of these failures that occur during training missions are delayed discrepancies, wherein the failure is not diagnosed until the pod's next scheduled maintenance action.

Given the assumption that deployed aircraft would receive their EW pod ILM at an OCONUS CIRF, analysis of usage rates and pipeline repair and transit times leads to the following deployment pod requirement rule: Two pods must deploy for each deployed aircraft equipped with an ALQ-184 or an ALQ-131, regardless of mission design series (MDS). Note that this implies that the full-deployment MRC scenario requires 996 ALQ-184 to support a deployment of 498 PAA. This suggests that the entire post-BRAC CONUS inventory of 643 ALQ-184 pods should be retained for deployment requirements, with no pods being retired because of BRAC-related PAA reductions.

Because 49 ALQ-131 pods have received the MIL-STD-1553 data bus card upgrade and each AFRC unit has 24 PAA, we assumed that all 49 upgraded pods were assigned to the Homestead AFRC unit in order to prevent the mixing of ALQ-131 pod modifications at any one site. We also assumed that each of the other five units, containing a total of 102 PAA, was assigned two ALQ-131 pods per PAA, producing a total MRC deployment requirement of 253 ALQ-131s. This suggests that even for a conservative estimate of deployment pod requirements, the entire post-BRAC CONUS inventory of 265 ALQ-131 pods exceeds these units' deployment requirements. BRAC-related PAA reductions may enable a small number of CONUS-assigned ALQ-131 pods to be reassigned to the OCONUS units currently operating the ALQ-131 pod at Spangdahlem and Aviano ABs.[5]

The deployment pod requirement computation resulted in a total CONUS-wide authorization of 643 ALQ-184 and 253 ALQ-131 pods. We then needed to determine the peacetime allocation of these ECM pods to individual units. Note that there are not enough ALQ-184 pods to satisfy the full deployment requirement for all ALQ-184–equipped aircraft, but that there are enough ALQ-131 pods to satisfy each unit's deployment requirement of two pods per ALQ-131–equipped PAA. Thus, each ALQ-131–equipped unit could receive a peacetime pod allocation equal to its deployment pod requirement.

However, consider the effect on an ALQ-131–equipped unit that sends its pods to an off-site CONUS CIRF for ILM. Recall that scheduled maintenance accounts for the majority of the ECM pod peacetime workload. Each pod requires an inspection at its ILM facility at its PMI even if unused since its last scheduled maintenance action. If this ALQ-131–equipped unit has a peacetime pod allocation equal to its deployment requirement of two pods per PAA, it is likely that a number of pods will return to the unit from its CIRF, remain unused for 180 calendar days, and then be sent back to the CIRF for a PMI.

Instead of transporting these unused pods between the unit and its CIRF, a peacetime pod requirement for CIRFed units can be computed in a manner similar to that used for the deployment requirement for ECM pods. Because this peacetime requirement will be less than the deployment requirement, the difference between the two could be stored at the CIRF, ready to deploy along with the supported unit. This would eliminate unnecessary transport of pods between the CIRFed unit and its CIRF. We assumed that any unit performing its own ECM pod ILM on site would keep its entire deployment pod requirement on site.

---

[5] While this analysis was limited to CONUS pod support, the finding that ALQ-131 requirements on a per-PAA basis are greater than the pre-BRAC allocations (265 pods/237 PAA pre-BRAC versus 253 pods/126 PAA computed requirement) suggests that these OCONUS units likely have a requirement for the 12 additional pods.

The goal for this peacetime pod requirement is to ensure that each CIRFed unit maintains at least one FMC pod on hand per PAA. Implementing commonly used USAF pipeline computations, we set the peacetime pod requirement for each CIRFed unit equal to the unit's PAA, plus the mean pipeline between the unit and its CIRF, plus one standard deviation of this pipeline, assuming an exceedingly conservative total base pipeline time of 14 calendar days. Further details on this computation are in Appendix D.

This logic produces CIRFed unit pod requirements of 22 ALQ-131s at 18 PAA units and 29 ALQ-131s at 24 PAA units. To illustrate how these pod allocations would work in practice, suppose that Atlantic City ANG (New Jersey) (18 PAA) and Davis-Monthan AFB (24 PAA) received ALQ-131 ILM from a CIRF at Burlington ANG (Vermont) (18 PAA). The peacetime allocation of pods would then be 22 at Atlantic City ANG, 29 at Davis-Monthan AFB, and 69 at Burlington ANG, with Burlington receiving its deployment requirement of 36 pods plus 14 additional pods from Atlantic City and 19 from Davis-Monthan.

When this computation is applied to the ALQ-184 pods, the total CIRFed unit pod requirement, summed over all units, exceeds the total pool of 643 ALQ-184 pods. Instead, it was assumed that these 643 pods were allocated proportionally to each unit's share of the total ALQ-184–equipped PAA. Note, however, that this computation does not necessarily imply that the ALQ-184 pod cannot be supported using CIRFs, because the 14-day CIRF pipeline time assumed here is very conservative. In upcoming sections, the optimization model will use actual transport, repair, and queueing times to determine the performance of CIRF networks for both the ALQ-184 and the ALQ-131.

EW Pod Cost and Performance Measures

The metric used to evaluate ECM-pod CIRF network performance is different from the serviceable spare count used in the engine analyses. Since the objective for ECM pods is to ensure that every deployed sortie has an ECM pod that is FMC, the metric used for the analysis is the ratio of FMC pods to assigned aircraft. This ratio is presented for both the CONUS and the deployed OCONUS fleets.

The number of FMC pods was computed as the total number of pods allocated to the theater (CONUS or OCONUS), minus pods that are INW, AWM, or AWP at an ILM facility, minus pods that are INT between an operating location and a CIRF. As with the JEIM analysis, we assumed that the location where ILM is performed would have no effect on average INW maintenance time, and that AWP rates would remain constant in CONUS independent of ILM locations.[6] Therefore, the structure of the CIRF network can affect the level of FMC pods through two counterbalancing effects:

1. changes in the number of pods expected to be INT, which would reduce the expected number of FMC pods as increasing workload is assigned to CIRFs
2. changes in the number of pods expected to be AWM, which would increase the expected number of FMC pods as increasing workload is assigned to CIRFs because of load balancing and queueing effects.

These expected FMC rates were assessed against the system cost necessary to achieve them. Two components were considered in the system cost: transport costs and operating costs. No CIRF setup cost was considered.

The transport costs were obtained from the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004), assuming an air-ride truck for each shipment and expedited service, dual drivers, constant surveillance service (CSS), and exclusive use. These transportation cost data include a scale of per-mile transport costs that depend on distance traveled. Because of uncertainties that arose about ECM pod transport costs during the course of this study, we assumed for this analysis that all ALQ-184 and ALQ-131 shipments would incur the maximum per-mile transport cost presented in the chart, $3.08. The

---

6 Because of the increased flying schedule associated with deployed operations, we assumed that deployed AWP rates increased proportionately with the increase in operating tempo between peacetime training and deployed operations.

transit times between bases were obtained using the DoD Standard Transit Time Guide—Truckload (U.S. DoD, 2006). An additional day was added to each transit leg to allow for transportation preparation time, and we assumed no pod transport pipeline time or transit cost for pods receiving ILM at their home-station bases. A one-way transit time of five days from any FOL to the OCONUS CIRF was assumed in keeping with the performance observed for the ALQ-131 during the USAFE CIRF test.[7] Note that OCONUS transit cost was not considered.[8]

The EW pod ILM operating cost was defined as the associated personnel cost using a factor of $60,000 per man-year.[9] Using data provided by Warner Robins Air Logistics Center (WR-ALC) from the Reliability, Availability, and Maintainability Data of Pods (RAMPOD) database,[10] we computed a peacetime ILM induction rate and a deployed failure rate for both the ALQ-184 and the ALQ-131. Further details on these computations are in Appendix D. WR-ALC also provided us repair time data on EW pods from RAMPOD.[11]

CONUS pod ILM shops were assumed to operate 16 hours per day, five days per week, and to require two eight-hour shifts per line and a 40-hour workweek per maintainer. The OCONUS CIRF

---

7 The USAFE CIRF test of September 2001 through February 2002 supported the ALQ-131 pod during both scheduled AEF rotations and OEF. During this test, 60 pods were serviced at the CIRF, with averages of 1.0 days of preparation time, 4.2 days of inbound transit (to the CIRF), and 3.7 days of outbound transit (from the CIRF). Note that there are no ALQ-184 pods assigned to USAFE units (the units at Aviano and Spangdahlem ABs use ALQ-131 pods), so ALQ-184 pods were not tested (see HQ USAF, 2002, p. 226).

8 OCONUS transport costs were not included because they are not affected by the CONUS CIRF network design. However, estimates of potential OCONUS-CONUS transport costs are presented later in this chapter (see Deployment Manpower Considerations).

9 This value is based on an estimate of the typical rank structure of an aircraft maintenance unit and the Office of the Under Secretary of Defense (Comptroller), Fiscal Year 2006 Department of Defense Military Personnel Composite Standard Pay and Reimbursement Rates, undated.

10 Data for January 2003 through June 2005 on ACC, AFRC, and ANG units provided by Malcolm Baker, WR-ALC/ITM, September 2005. Data for January 1999 through January 2004 provided by Malcolm Baker, WR-ALC/ITM, May 4, 2004.

11 Personal communication, Robbie Ricks, WR-ALC/ITM, via email, February 2004.

was assumed to operate 24 hours per day, seven days per week, with two daily shifts of 12 hours each and a 60-hour workweek per maintainer. We performed an LCOM simulation analysis to identify the potential for economies of scale in EW pod ILM shops in a similar manner to that used for JEIM shops (as discussed in Chapter Three). These analyses indicated that relatively small economies of scale (compared with those found for JEIM) were potentially achievable for EW pod ILM shops, primarily stemming from the increased utilization of personnel. As with the engine analyses, maintenance manpower was adjusted using man-hour availability factors, with additional management and support positions added to the requirement. No differentiation was made between different "types" of full-time manpower (e.g., active duty versus ANG). It was assumed that OCONUS FOLs sent all ECM pod failures to either the ALQ-184 or ALQ-131 OCONUS CIRF, as appropriate. We assumed that the ALQ-184 OCONUS CIRF was staffed entirely by personnel deploying from the ALQ-184 CONUS CIRFs. Similarly, we assumed that the ALQ-131 OCONUS CIRF was staffed entirely by personnel deploying from the ALQ-131 CONUS CIRFs.

Cost-Performance Tradeoff Evaluated Against Deployment Scenario

We used the optimization model presented in Chapter Two to identify the most cost-effective CIRF solutions and thus demonstrate the best system performance available for any level of expenditures. The analysis methodology is demonstrated here for the ALQ-184; Appendix D offers a more detailed treatment of this methodology for each pod type.

The CONUS ALQ-184 units under consideration account for 150 A-10/OA-10 PAA and 348 F-16 PAA. The 20 percent deployment scenario, as described in Appendix B, accounts for a deployment of 30 ALQ-184–equipped A-10 PAA and 70 ALQ-184–equipped F-16 PAA. It was assumed that all deployed ALQ-184 pods were supported using a single OCONUS CIRF. This ALQ-184 deployment scenario of 30 A-10/OA-10s and 70 F-16s has a total pod requirement of 200 deployed ALQ-184s.

It is important to note that the previous two sections' analyses were used solely to determine pod deployment requirements and peacetime pod allocations. As with the JEIM analyses, the optimization model presented in Chapter Two was used to determine the efficient frontier cost-performance curves and to identify an alternative ALQ-184 CIRF network as well as an alternative ALQ-131 network.

An AN/ALM-233D electronic test stand is required to perform ALQ-184 ILM. Pre-BRAC, 36 AN/ALM-233D test stands were assigned to CONUS units. It was assumed that no additional test stands could be procured. These test stands are themselves subject to periodic failures. An analysis of data provided by WR-ALC suggests that the AN/ALM-233D could be expected to maintain a mean FMC rate of 88.0 percent.[12] Appendix D provides more details on this computation. It was further assumed that any test stand that was less than FMC could not be used to perform pod ILM.

Four years' worth of pod status data were provided by WR-ALC/ITM.[13] They indicated that, on average, 3.3 percent of ALQ-184-Long pods were AWP worldwide at any point in time. However, these AWP rates would be expected to increase in a deployment because of the deployed flying schedule's higher operating tempo. We increased the deployed pod AWP fraction in proportion to the deployment scenario's increased pod failure rate compared against its peacetime ECM pod ILM induction rate. The AWP rate of 3.3 percent for ALQ-184 was unchanged for the CONUS pod remainder. Applying this increased AWP rate to the deployment size of 200 ALQ-184 pods gave a mean expectation of 15.1 AWP pods, with another 14.6 pods AWP at the CONUS units. Given the assumed repair rates, and accounting for the differences in CONUS and OCONUS work schedules and flying schedules, a mean of 7.1 ALQ-184 pods is expected INW at the

---

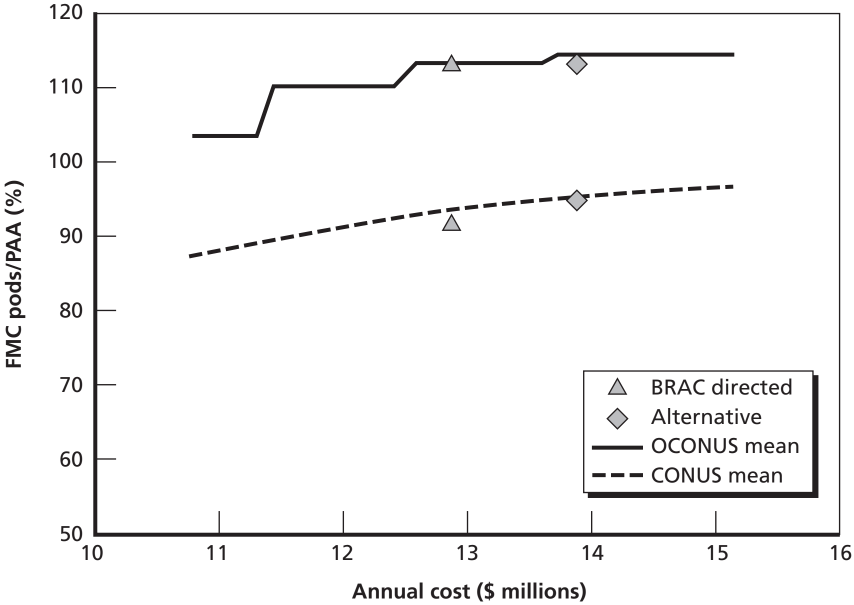
[12] Data for July 2003 through February 2004 provided by Malcolm Baker, WR-ALC/ITM, May 4, 2004.

[13] Data for January 2000 through December 2003 provided by Robbie Ricks, WR-ALC/ITM, February 2004.

OCONUS CIRF, with an overall mean of 14.4 ALQ-184 pods INW across all CONUS units, independent of the CONUS ILM network. Note that the OCONUS INT pipeline, containing a mean of 62.6 ALQ-184 pods, is also independent of the CONUS ILM structure. These considerations yield a maximum possible mean FMC value of 115 ALQ-184 pods OCONUS and 414 ALQ-184 pods CONUS (assuming zero pods AWM and zero pods in the CONUS INT pipeline). Because the deployment scenario accounts for 100 total ALQ-184–equipped PAA deployed OCONUS and 398 total ALQ-184–equipped PAA remaining in CONUS, the maximum possible mean ratio of FMC ALQ-184 pods to PAA is 115 percent OCONUS and 104 percent CONUS.

Figure 4.3 presents the results of the deployment scenario analysis for the ALQ-184 ILM structure, demonstrating the tradeoff between annual cost (transport cost plus operating cost) and the achieved ratio of FMC pods to PAA, for both the CONUS and the OCONUS fleets. The optimization model presented in Chapter Two was used to identify the points defining these curves, which demonstrate the best system performance available for any level of expenditures. Note that best system performance in this case refers to the maximum total number of FMC pods systemwide (both CONUS and OCONUS). Also note that these efficient frontier curves actually represent a very large number of potential solutions: For any level of expenditures along these curves (e.g., 110 percent FMC/PAA OCONUS, 91 percent FMC/PAA CONUS, at a total cost of $12 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the ALQ-184–equipped CONUS PAA, the mean ALQ-184 FMC level can be kept above 100 percent with respect to OCONUS aircraft, although the CONUS remainder cannot be supported at a mean FMC level of 100 percent with respect to PAA due to the large number of spare pods that were deployed OCONUS. What prevents CONUS performance from reaching its upper bound of 104 percent FMC/PAA is the limited number of test stands. If there is no limit on the maximum number of maintenance lines (as in the engine analyses), CONUS performance will approach its maximum of 414 FMC

Figure 4.3
Deployment Scenario, ALQ-184 CIRF Network Options



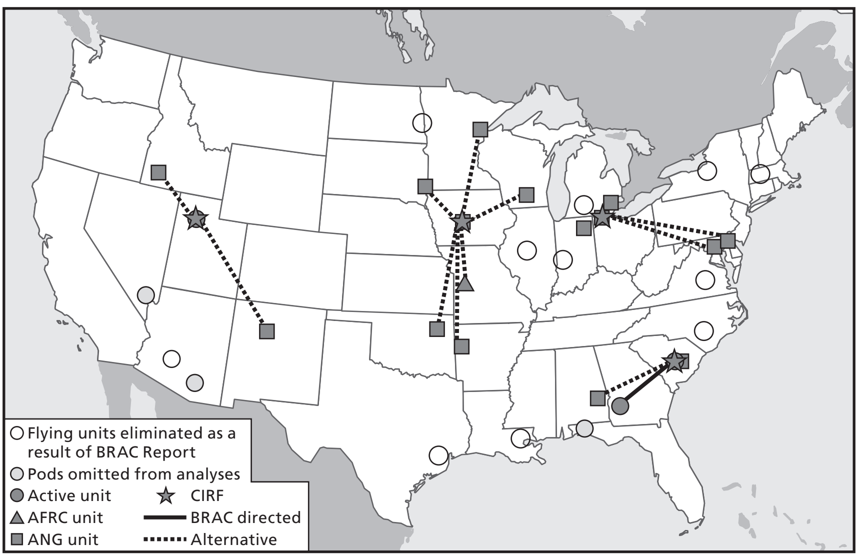
RAND *MG418-4.3*

pods. However, the constraint of 36 total test stands available leads to a significant number of pods remaining in AWM status, preventing this maximum performance level from being achieved. Recall that all deployed ECM pods receive ILM at an OCONUS CIRF. Because a five-day transport time was assumed between all FOLs and the OCONUS CIRF, OCONUS performance is strictly a function of the number of test stands placed at the OCONUS CIRF, leading to a performance curve that resembles a step function.

Ideally, we would like to compare this range of alternative CIRF network designs to the current decentralized ILM system in terms of cost and performance. Although historical cost and performance data were collected, they do not reflect the post-BRAC force structure. Moreover, the worldwide pod availability data do not reflect the same deployed flying schedule (this four-year period includes support of OEF and OIF), making direct comparison with these results somewhat difficult. Most significantly, this single historical worldwide FMC rate does not differentiate between deployed pod and CONUS pod availability. To provide a more appropriate basis for comparison, we evaluated the post-BRAC ALQ-184 network presented in Figure 4.1 using the optimization model. It achieved a mean of 113 percent FMC/PAA OCONUS, 92 percent FMC/PAA CONUS, at a total cost of $12.9 million.

While the post-BRAC ALQ-184 network is rather cost-effective (i.e., it lies very near both efficient frontier curves), other solutions lying on the efficient frontier curves could be selected. For example, for a desired performance goal of 95 percent FMC/PAA CONUS, a solution could be identified on the efficient frontier curves of Figure 4.3 to meet this standard at a minimum total cost of $13.9 million. The network configuration associated with this alternative solution is presented in Figure 4.4. It is important to note that the curves appearing

Figure 4.4
Alternative CIRF Network, ALQ-184



RAND *MG418-4.4*

in Figure 4.3 are rather flat in the vicinity of the alternative solution, suggesting that one could identify alternative CONUS CIRF network designs differing only slightly in performance from this alternative that may, based on considerations outside the scope of our analysis, be preferable.

Note that both solutions maintain an OCONUS FMC pod level exceeding the deployed aircraft requirement. Recall that the computation of the deployment pod requirement assumed a two-day delay time at the CIRF to account for INW and AWM time. The mean repair time for an ALQ-184 pod is 27.2 hours. Since the OCONUS CIRF operates 24 hours per day, seven days per week, the mean INW time per ILM induction will be slightly more than one day. Because this optimization analysis computes the actual mean AWM time given a number of test stands at the OCONUS CIRF, as more test stands are added to the OCONUS CIRF, the mean AWM time can decrease to a level such that the total CIRF delay time is less than two days. In this case, the deployment pod allocation would provide for more pods than are needed.

Note, however, that the performance presented in Figure 4.3 is average performance over time. At any point in time, actual system performance would be expected to vary around this mean. Because it is necessary to have an FMC pod for each deployed sortie, this mean value should be greater than 100 percent. For both the alternative CIRF network and the post-BRAC network, the OCONUS ratio of FMC ALQ-184 pods to deployed aircraft lies between 108 percent and 120 percent one-half of the time (exceeding this interval one-quarter of the time, and lying below this interval one-quarter of the time).

The alternative CIRF network has a total full-time manpower requirement of 183: a total manning of 117 at the CONUS CIRFs and 66 manpower positions at the OCONUS CIRF. The post-BRAC network has a total full-time manpower requirement of 207: a total manning of 141 at the CONUS ILM facilities and 66 manpower positions at the OCONUS CIRF. The alternative solution requires a total of 21 test stands at CONUS CIRFs and 10 test stands at the OCONUS CIRF; the post-BRAC network requires a total of 24 test stands at CONUS ILM facilities and 10 test stands at the OCONUS CIRF.

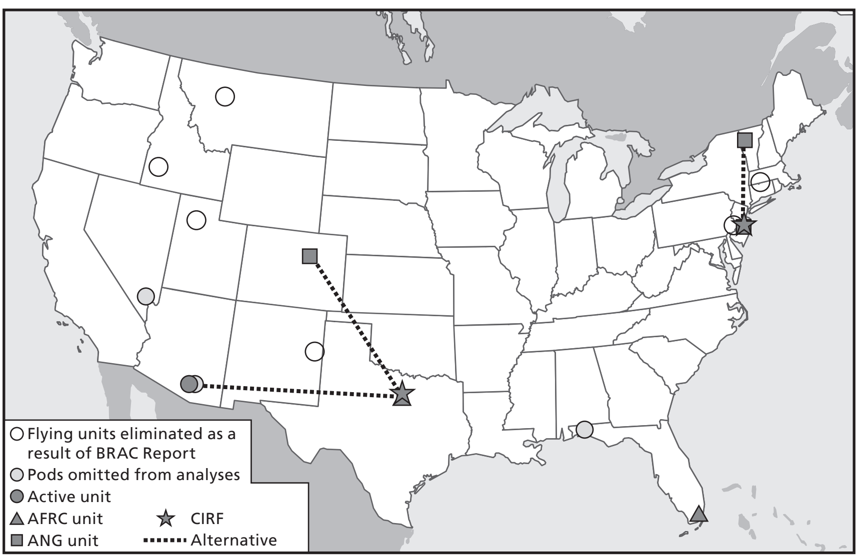
Notice that the alternative solution requires 24 fewer full-time maintenance positions but greater expenditures for CONUS transportation—transport costs of $2.9 million for the alternative solution and $0.4 million for the BRAC-directed network.

This analysis methodology was also applied to the ALQ-131 pod (detailed in Appendix D), producing the alternative CIRF network design in Figure 4.5 (which assumes that Homestead AFRC possesses all 49 AFRC-upgraded pods).

Deployment Manpower Considerations

The manpower requirements associated with the alternative solutions place a heavy deployment burden on ALQ-184 and ALQ-131 maintenance personnel. If the alternative network's total CONUS ALQ-184 manning of 117 personnel is used to support its OCONUS manpower

Figure 4.5
Alternative CIRF Network, ALQ-131



RAND *MG418-4.5*

requirement of 66 positions, all full-time ALQ-184 ILM personnel would have to spend more than one-third of their time deployed OCONUS (a similar deployment burden was observed for the ALQ-131) under our deployment scenario. Unfortunately, the alternative policies that were used to mitigate the deployment burden on engine maintenance personnel are less applicable to ECM pod maintenance. For F110 and F100 engines, a subset of retained tasks that would be performed at the OCONUS CIRF was identified in an attempt to strike a balance between the opposing demands of limiting deployed personnel and limiting OCONUS-CONUS transport. The retained task concept does not apply to ECM pods, however, since the extent of a pod failure cannot be determined without first testing the pod using the test stand. Once the pod failure has been identified on the test stand, pod maintenance is a relatively easy task, provided that the needed parts are on hand. Thus, the retained task option is precluded.

The alternative policy used to limit deployment burden on TF34 engines was to perform all TF34 JEIM, for both CONUS and OCONUS aircraft, at CONUS CIRFs. While such a policy eliminates the deployment burden on maintenance personnel, it imposes a burden on strategic lift between OCONUS and CONUS. For the TF34 engine, the deployment scenario has an annual requirement of 82 engine shipments (each way) between the FOLs and CONUS CIRFs. Because of the higher frequency of ECM pod failures, such an "all repair in CONUS" policy would require 2,285 ALQ-184 pod shipments (each way) annually between the FOLs and CONUS CIRFs. While it is true that multiple failed pods could to some extent be batched together and transported in the same shipment, this would still place a heavy burden on strategic lift assets. Another detriment to this policy is that additional pods would be needed at OCONUS FOLs to account for the longer pipelines associated with the longer OCONUS-CONUS transport leg, which would further degrade the availability of pods at CONUS units. This would be especially problematic for the ALQ-184. Also, recall that the cost of transport from OCONUS FOL to OCONUS CIRF has not been included in this analysis. The cost to transport an ECM pod at the AMC channel rate between Dover AFB and Al Udeid AB (for example) is $1,693 each way per ALQ-184.[14] The annual transit cost to ship all 2,285 ALQ-184 pod shipments round-trip would thus be $7.7 million. These OCONUS transit costs would be rather expensive relative to their associated manpower costs.

Suppose these transport limitations preclude the use of such a policy of all repair in CONUS. Assume a goal that is consistent with the general AEF construct, wherein full-time USAF personnel are eligible to spend one-fifth of their time deployed, implying that five full-time manpower positions are required systemwide to support one perpetually deployed position.[15] If all positions are to be filled by full-time personnel, the 66 full-time ALQ-184 positions required at the OCONUS CIRF will require 330 full-time manpower positions systemwide. This is an increase of 147 positions beyond the alternative solution's full-time manning of 183. At any point in time, 264 of these full-time ALQ-184 positions would be in CONUS, which is much larger than the 117 manpower positions required for the residual CONUS fleet's workload. This amounts to an increase of 126 percent over the required full-time CONUS ALQ-184 ILM manning, implying that the CONUS workforce would be greatly underutilized.

Part-Time Manning Considerations

An alternative policy for ECM pod ILM that would decrease the deployment burden on full-time personnel is to use activated part-time personnel to fill some fraction of the full-time manpower positions required to support this 20 percent deployment scenario. Recall that the alternative solution has a CONUS full-time manning of 117 for the ALQ-184. This number of CONUS positions could be used to support 29 permanently deployed positions, in which case the associated deployment burden would not exceed one-fifth. This leaves an

[14] ALQ-184-Long weight is 635 lb (Raytheon Company, 2005); AMC channel rate between Dover and Al Udeid AFBs is $2.666 per lb each way (U.S. Government, 2005).

[15] For the TF34, we used a work schedule of two shifts, 16 hours per day, five days per week.

additional 37 full-time ALQ-184 positions at the OCONUS CIRFs. Suppose these 37 positions were to be filled by activated part-time personnel, and assume that each part-time drill position incurs a cost of $15,000. The current AEF cycle calls for forces to meet a 120-day eligibility window over a 20-month cycle. Assume that reserve component personnel could be activated once every two AEF cycles. This implies that reserve component personnel could expect to be activated one-tenth of the time over a 40-month period. If these 37 OCONUS CIRF positions were to be filled by activated part-time personnel, observing such guidelines would require 370 total part-time personnel. These two policies can be evaluated by comparing the cost of staffing 370 part-time positions ($5.6 million) versus the cost of filling an additional 147 full-time positions ($8.8 million). Note that the cost of the 37 activated part-time positions is not an additive cost to the policy of using part-time personnel in this case. A mix of full-time and part-time staffing, between these two extremes, is also possible to address other considerations. A similar examination was performed for the ALQ-131; details are in Appendix D.

This is very different from the part-time personnel computations made for the engine analyses. For those, the part-time manning requirement was determined from the MRC scenario, and the part-time personnel were not needed to support the 20 percent deployment scenario. The 370 part-time ALQ-184 personnel associated with this ECM pod analysis are needed to support the 20 percent deployment scenario. However, a different analysis is needed to determine the part-time ECM pod personnel necessary for the MRC scenario.

If ILM manpower is designed to support sustained deployment operations with an assumed workload of 24 hours per day, seven days per week shop operations, and a 60-hour workweek (as is the OCONUS CIRF policy), little additional capacity is available to support more-stressing, surged operations. Manpower and test stands operating at CONUS CIRFs could support a heavier workload during surged operations, especially if deployed, through utilization in a 60-hour workweek environment. However, the total number of test stands available is likely to be the limiting factor in such a large deployment.

Consider the MRC scenario presented earlier in determining the part-time manning requirement in the reserve component. Recall that all ALQ-184–equipped squadrons in this analysis are combat coded, which means there is no need to retain any test stands at CONUS units in this scenario. Because there are 36 AN/ALM-233D test stands available, we can assume the OCONUS CIRF in each theater operates 18 AN/ALM-233D test stands. This would require a total manning of 119 positions at each ALQ-184 CIRF, for a total MRC manning of 238 positions. This MRC manning for the ALQ-184 is less than the total manning required to support the 20 percent deployment scenario if either of the policy options presented above is used to maintain a deployment burden of no greater than one-fifth for the 20 percent deployment scenario.

However, for the ALQ-131, this MRC manning is higher than the total manning required to support the 20 percent deployment scenario for both policies used to maintain a deployment burden of no greater than one-fifth. This difference between the two pod types results from the relative scarcity of AN/ALM-233D test stands compared with the number of AN/ALM-256 test stands (used for ALQ-131 ILM), considered in light of the workload requirement for each. There are more than 2.5 times as many ALQ-184 pods as ALQ-131 pods in this analysis, and ALQ-184 pods have a failure rate twice that of the ALQ-131; yet there are only 1.8 times as many AN/ALM-233D test stands as AN/ALM-256 test stands.

Output Tables

The efficient frontier curves presented in Figure 4.3 represent a very large number of potential solutions. Each point on the two curves is associated with a specific CIRF network design. Table 4.2 summarizes, for all policies considered, the maintenance and transportation costs and the system performance and manpower requirements related to the 20 percent deployment scenario for both the post-BRAC and the alternative ALQ-184 CIRF networks. Note that costs include part-

Table 4.2
Cost and Performance for ALQ-184 CIRF Networks

	BRAC Directed		Alternative	
Maintenance locations (CONUS/OCONUS)	18/1		4/1	
FMC pods/PAA (%)				
CONUS	92		95	
OCONUS	113		113	
Transportation ($M)	0.4		2.9	
Mean transport pipeline				
CONUS pods	3.3		25.1	
OCONUS pods	62.6		62.6	
Means for managing deployment burden	Additional full-time personnel	Activated part-time personnel	Additional full-time personnel	Activated part-time personnel
Payroll ($M)	19.8	17.1	19.8	16.5
Total ($M)	20.2	17.5	22.7	19.4
Manning				
CONUS full-time	264	141	264	117
CONUS part-time	0	310	0	370
OCONUS full-time	66	66[a]	66	66[a]

[a] Some of these personnel are also counted under CONUS part-time when activated part-time personnel are used to manage the deployment burden.

time personnel positions, which were not considered in the optimization procedure used to generate Figure 4.3. Table 4.3 presents similar information for the ALQ-131 pod.

As can be seen in these two tables, some OCONUS full-time personnel are also counted as CONUS part-time personnel when activated part-time personnel are used to manage the deployment burden.

Table 4.3
Cost and Performance for ALQ-131 CIRF Networks

	BRAC Directed		Alternative	
Maintenance locations (CONUS/OCONUS)	6/1		3/1	
FMC pods/PAA (%)				
CONUS	163		173	
OCONUS	120		120	
Transportation ($M)	0.0		0.7	
Mean transport pipeline				
CONUS pods	0.0		3.5	
OCONUS pods	8.8		8.8	
Means for managing deployment burden	Additional full-time personnel	Activated part-time personnel	Additional full-time personnel	Activated part-time personnel
Payroll ($M)	5.1	4.2	5.1	4.1
Total ($M)	5.1	4.2	5.8	4.8
Manning				
CONUS full-time	56	36	56	34
CONUS part-time	62	82	62	84
OCONUS full-time	14	14[a]	14	14[a]

[a] Some of these personnel are also counted under CONUS part-time manning when activated part-time personnel are used to manage the deployment burden.

Under such a policy, activated part-time personnel would incur both their part-time manning cost and the associated full-time manning cost, since these activated positions would be constantly maintained by a rotation of part-time personnel.

The limitations imposed by the deployment burden lead to the gains associated with centralization of ALQ-184 maintenance being less than the gains identified for TF34, F110, and F100 JEIM. Because of the small scale of the ALQ-131 network, the benefits associated with centralization of ALQ-131 maintenance are also much less than those achieved in the JEIM analyses. The uncertainties related to deployed pod failure rates also lessen the strength of the ECM CIRF recommendations. However, these results indicate that a small number of ALQ-184 and ALQ-131 CIRFs can provide both a cost-effective solution and acceptable performance.

CHAPTER FIVE

F-15 Avionics and LANTIRN Results

The final two classes of commodities that were included in the scope of our analysis were F-15 avionics and LANTIRN pods. Two reasons prevented us from including the internal avionics for fighter and attack aircraft other than F-15s: (1) F-16 avionics maintenance is currently performed at only two levels, with no ILM at the operating units (although units do maintain a limited ability to validate LRU failures); and (2) A-10 avionics maintenance uses manual test and repair, as opposed to ATE, and is thus not believed to have the potential for large savings resulting from consolidated ILM.

F-15 Avionics

The F-15 aircraft system has 63 avionics LRUs that require ILM, including instrumentation, displays, flight computers, navigation systems, EW, and sensor equipment. Currently, ILM for avionics is conducted in the context of an avionics back-shop within the wing component maintenance squadron (CMS) at each location. ILM for an LRU is performed using one of three types of automatic test stations: the AN/GSM-397(V) electronic system test set (ESTS), TISS, and antenna (ANT) A/B. The ESTS is a second-generation test station that replaces five individual stations in the original F-15 avionics intermediate system (AIS). Unlike other commodities, such as engines, whose assets can be expected to undergo ILM for days or weeks, the expected time to test, repair, and return to service an avionics LRU is relatively short, ranging from one to 52 hours, with all but a few of the LRUs requiring less than ten hours. Another important distinction between F-15 avionics and engines is that an LRU may occasionally fail the on-aircraft diagnostic test only to have no failure identified in subsequent testing on the automatic test station. Such situations are declared to be BCS events, and the LRUs are returned to the serviceable inventory.

Following implementation of the BRAC recommendations, F-15 units will remain at 13 CONUS locations.[1] These include five active component locations and six ANG locations, as shown in Table 5.1, with a total PAA of 186 F-15C/D and 134 F-15E aircraft. This set of 11 CONUS locations currently accounts for a total of 32 ESTSs, 17 TISSs, and 30 ANT A/B sets.

Under the BRAC Report recommendations, one avionics CIRF will be established at Tyndall AFB and will service LRUs from the F-15s remaining at Langley AFB and from its own F-15s, as shown in Figure 5.1.

Concept of Operations

Within CONUS, any F-15 avionics LRU that fails its built-in test (BIT) on the aircraft is removed. For locations without an ILM facility, the LRU is prepared for transport and sent to the designated CIRF via express shipping under the Military Surface Deployment and Distribution Command's (SDDC's) Domestic Small Package Express Blanket Purchase Agreements under two-day air (with a third day allotted for processing). On arrival at the ILM facility, the item is repaired through replacement of SRUs as identified on the test station, and the LRU is returned to serviceable condition. Occasionally, the ILM facility is not able to repair the LRU, in which case it is sent to the depot as not repairable this station (NRTS).

---

[1] Nellis AFB F-15 avionics are contractor supported in the BRAC Report and are thus excluded from this analysis. Edwards AFB F-15s are also excluded, in this case because of the unit's special AFMC testing mission. These two units appear as light gray circles in Figure 5.1.

Table 5.1
Post-BRAC F-15 Operating Locations

		PAA	
Base Name	**MAJCOM**	**F-15C/D**	**F-15E**
Eglin AFB (Florida)	AFMC/ACC	15	5
Langley AFB (Virginia)	ACC	18	
Seymour-Johnson AFB (North Carolina)	ACC		87
Mountain Home AFB (Idaho)	ACC		42
Tyndall AFB (Florida)	AETC	48	
Jacksonville ANG (Florida)	ANG	18	
New Orleans ANG (Louisiana)	ANG	18	
Great Falls ANG (Montana)	ANG	15	
Barnes ANG (Massachusetts)	ANG	18	
Portland ANG (Oregon)	ANG	18	
Kingsley ANG (Oregon)	ANG	18	

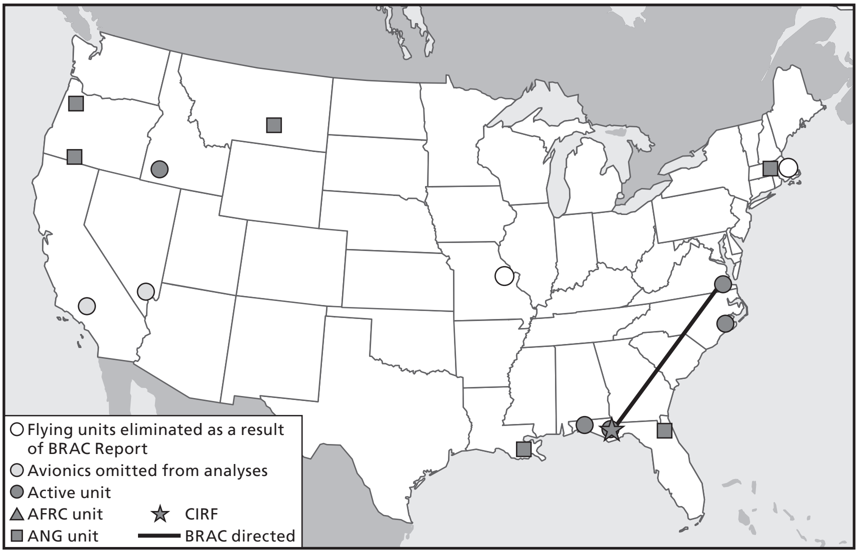
SOURCES: 2005 Defense Base Closure and Realignment Commission, 2005; AF/XPPE, FY06PB_Mar05_acftmsls3.xls, AF Program Data System, 2005.

NOTE: MAJCOM = major command; AETC = Air Education and Training Command.

Spare LRUs are therefore found in the following locations:

- spares inventory at operating locations
- INT to CIRF (transit pipeline)
- INW/AWM/AWP at CIRF (maintenance pipeline)
- INT back to operating location
- INT to depot (NRTS)
- INW/AWM/AWP at depot (NRTS).

Figure 5.1
Post-BRAC Network, F-15 Avionics



RAND *MG418-5.1*

Authorized inventory levels within CONUS for each of the LRUs were obtained from the Central Leveling Summary (CLS) of the Readiness-Based Leveling database.[2] The average number of LRUs that would be INT is based on the fleetwide failure rate and the flying schedule along with an assumed total transit time of six days. The deployment scenario involves the sustained deployment of 20 percent of the combat-coded CONUS PAA. For OCONUS-deployed units, the round-trip transit time to an OCONUS CIRF is assumed to be 15 days. The spares requirement to support depot operations was computed using the current NRTS occurrence rates along with the average times spent at the depot (also in the CLS).

Typically, there are more spares than required to support transportation and maintenance pipelines. However, there are a few LRUs for which the number of spares is small, less than one per operating base. For these critical items, we assumed that spares are allocated first

---

[2] Nellis and Edwards AFBs are not included, for the reasons mentioned earlier.

to bases without maintenance facilities, and then determined the fraction of time during which a spare would not be available for an aircraft at a location without ILM on site.

Each of the three test stations—ESTS, TISS, and ANT A/B—requires two operators per shift. We further assumed that there are two shifts and one supervisor and that 10 percent are overhead personnel, for a total of 5.5 full-time personnel per test station. For CONUS locations, we assumed shifts of eight hours, five days per week. For OCONUS, we assumed two shifts at ten hours per day, six days per week. We also assumed 85 percent utilization for each station so as to limit the number of LRUs in AWM status. Table 5.2 presents cost and performance data on the current F-15 avionics ILM network along with the BRAC-directed network.

As stated above, we minimized the effect of critical items by assuming that available spares are allocated to bases without ILM. Because avionics LRUs are normally repaired within a few hours, we were able to assume that bases with on-site ILM could return an LRU to service without causing an aircraft to be unavailable because it lacked the LRU. In both the current and BRAC-directed networks, because most operating locations are self-supporting, the number of aircraft that are not mission capable, supply (NMCS) because of critical LRUs that are INT or INW is low.

Alternative CIRF Configuration

One alternative to the BRAC Report recommendations is a CIRF configuration that establishes three CIRFs—one each in the northwestern, northeastern, and southeastern United States—as shown in Figure 5.2.[3] This CIRF network moves ILM support for Langley AFB from Tyndall AFB (as directed in the BRAC Report) to Barnes ANG (Massachusetts). Seymour-Johnson AFB (North Carolina) and Mountain Home AFB (Idaho), locations that operate only the F-15E, retain home-station ILM support in this network design. Note that this CIRF configuration was not determined using the optimization procedure described in Chapter Two.

---

3 Excluding Nellis and Edwards AFBs, for the reasons mentioned earlier.

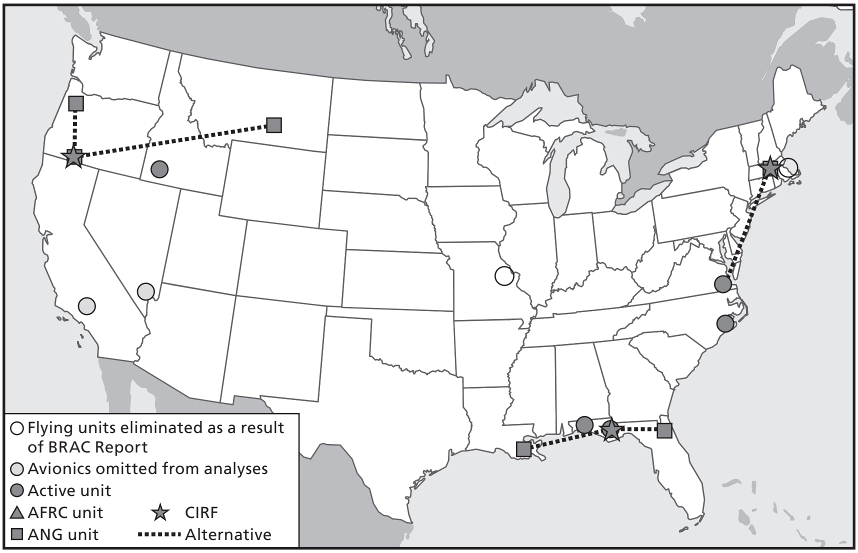
Table 5.2
Cost and Performance for F-15 Avionics BRAC-Directed CIRF Network

	Current	BRAC Directed
Maintenance locations (CONUS/OCONUS)	11/1	10/1
Transportation ($M)	0.0	0.1
Mean transport pipeline		
CONUS LRUs	0	13
OCONUS LRUs	198	198
Mean critical item pipeline		
CONUS LRUs	0.0	0.6
OCONUS LRUs	24.1	24.1
Test sets (CONUS/OCONUS)		
ESTS	22/6	21/6
TISS	20/3	18/3
ANT	20/4	18/4
Payroll ($M)	24.8	23.2
Total ($M)	24.8	23.3
Manning		
CONUS	341	314
OCONUS	72	72

Table 5.3 shows the estimated costs and performance of the alternative CIRF network design having three CIRFs in addition to two active duty stand-alone bases. As smaller bases are assigned to a CIRF, test equipment utilization increases, leading to a decrease in the total number of test stations required and to a savings in manpower.

This suggests that using three CONUS CIRFs (and two stand-alone locations) leads to a decrease of four ESTSs, seven TISSs, and six ANT sets from consolidation, with a resulting decrease in manpower

Figure 5.2
Alternative CIRF Network, F-15 Avionics



RAND *MG418-5.2*

costs of $5.7 million. This decrease is accompanied by increased transportation costs of some $300,000 annually.

In addition, the expected number of aircraft unavailable because of critical items INT increases by approximately three. Since this design has more bases without on-site ILM, it is not always possible to allocate spares of critical LRUs to each such base. At this point, the six-day transit to and from each CONUS CIRF significantly impacts the LRU availability.

Evaluation of BCS Screening of Avionics LRUs

An alternative CONUS CIRF operational concept includes prescreening of removed LRUs at the aircraft operating location to detect BCS conditions before sending the LRUs to CIRFs. On occasion, an LRU will fail the on-aircraft BIT check but then exhibit no failure when examined on the test station. Since a BCS situation can be detected in less time than a full repair takes, and since this check requires no spare SRUs, it might seem advantageous to assign test stations to locations

Table 5.3
Cost and Performance for F-15 Avionics CIRF Networks

	BRAC Directed	Alternative
Maintenance locations (CONUS/OCONUS)	10/1	5/1
Transportation ($M)	0.1	0.4
Mean transport pipeline		
CONUS LRUs	13	80
OCONUS LRUs	198	198
Mean critical item pipeline		
CONUS LRUs	0.6	3.4
OCONUS LRUs	24.1	24.1
Test sets (CONUS/OCONUS)		
ESTS	21/6	17/6
TISS	18/3	11/3
ANT	18/4	12/4
Payroll ($M)	23.2	17.5
Total ($M)	23.3	17.9
Manning		
CONUS	314	220
OCONUS	72	72

without LRU repair capability so as to identify these LRUs and avoid transporting them to CIRFs. Table 5.4 examines the effects of employing such a BCS screening policy for the alternative CONUS CIRF network design.

BCS screening does decrease the expected number of LRUs INT, since BCS LRUs are returned to inventory without being transported to a CIRF. However, additional test stations are needed to provide for BCS screening at bases without avionics ILM facilities. This increase

Table 5.4
Cost and Performance Considering Effect of BCS Screening on F-15 Avionics Alternative CIRF Network

	Without BCS Screening	With BCS Screening
Maintenance locations (CONUS/OCONUS/BCS)	5/1/0	5/1/6
Transportation ($M)	0.4	0.2
Mean transport pipeline		
CONUS LRUs	80	59
OCONUS LRUs	198	198
Mean critical item pipeline		
CONUS LRUs	3.4	2.5
OCONUS LRUs	24.1	24.1
Test sets (CONUS/OCONUS)		
ESTS	17/6	22/6
TISS	11/3	16/3
ANT	12/4	18/4
Payroll ($M)	17.5	22.8
Total ($M)	17.9	23.0
Manning		
CONUS	220	308
OCONUS	72	72

in test stations needed for BCS screening is greater than the reduction in test stations at the CIRFs that results from the decreased CIRF workload due to BCS. This effect is primarily caused by the increase in *total* workload associated with a BCS screening policy. All LRUs failing the on-aircraft BIT check must be tested to determine which are BCS. The test station time required to screen an LRU is a significant fraction of the total time it would take to repair the LRU if it proved to be necessary; and for LRUs that fail the BCS screen and are sent to the CIRF for repair, this testing must be repeated as part of the repair process. Thus, BCS screening can create a significant increase in the total system maintenance workload.

Whether BCS screening is a cost-effective policy depends on the situation. Specifically, it depends on the relative frequency of BCS events and the ratio of screening time to repair time. For F-15 avionics LRUs, under the alternative CIRF network, the use of a BCS screening policy increases the payroll cost by $5.3 million while reducing the transport cost by only $0.2 million, producing a net cost increase of $5.1 million. The 28 percent increase in total system cost associated with a BCS screening policy results in the removal of only 0.9 critical item LRUs from the mean transport pipeline. For this scenario, BCS screening for F-15 avionics LRUs does not appear to be cost-effective. Additionally, the BCS screening policy requires a total of 19 TISS test stations across both CONUS and OCONUS sites, exceeding the 17 TISS test stations available at the units under consideration.

OCONUS Manning Issues

The AEF concept implies that OCONUS CIRF full-time staffing should represent no more than one-fifth of the total systemwide requirement. For F-15 avionics, an OCONUS CIRF staffing of 72 positions implies a requirement for a total of 360 full-time systemwide (i.e., CONUS plus OCONUS CIRF) authorizations. Under the BRAC-directed network, the 386 total manpower positions would be adequate to support this OCONUS rotation goal of no more than one in five full-time personnel positions deployed OCONUS at any point in time. Under the alternative CIRF plan, the 220 full-time maintenance positions within CONUS can support such a deployment burden requirement for only 55 OCONUS CIRF positions, resulting in a shortfall of 17 full-time maintenance positions OCONUS. One solution is to size the CONUS workforce such that OCONUS deployment requirements represent no more than 20 percent of the total CONUS workforce. As Table 5.5 shows, this would result in a total of 360 maintainers, some of whom would represent excess manning at CONUS ILM facilities. Another option is to activate part-time maintainers from the reserve

Table 5.5
F-15 Avionics Manning Requirements for Two OCONUS CIRF Staffing Policies, Alternative CIRF Network

	All Full-Time Personnel	Maximum Use of Part-Time Personnel
Manning		
CONUS full-time	288	220
CONUS part-time	0	170
OCONUS full-time	72	72[a]
Payroll ($M)	21.6	20.1

[a] Seventeen of these personnel are also counted under CONUS part-time manning when activated part-time personnel are used to manage the deployment burden.

component. If a reserve component part-time maintainer is called up once every other AEF cycle (i.e., one in ten maintainers are activated at any point in time), this policy implies a total of 170 part-time maintainers, in addition to the 275 full-time maintainers determined previously. As Table 5.5 indicates, 17 of the personnel for OCONUS full-time manning are also counted under CONUS part-time manning when activated part-time personnel are used to manage the deployment burden. Under such a policy, activated part-time personnel would incur both their part-time manning cost and the associated full-time manning cost, since these activated positions would be constantly maintained by rotation of part-time personnel.

These two policy options represent two extremes. One fills all requirements using full-time personnel, resulting in overstaffed CONUS ILM locations because a number of the full-time personnel are there to support OCONUS rotation requirements rather than to fill demands based on the CONUS workload. The other extreme uses part-time members of the reserve component to fill the OCONUS workload not supported by the full-time maintenance workforce determined by the CONUS workload. Any mix of full-time and part-time staffing that falls between these two extremes could be selected based on other considerations.

LANTIRN

The LANTIRN pods come in two forms, the AN/AAQ-13 navigation (NAV) pod and the AN/AAQ-14 targeting (TGT) pod. These pods enable F-15Es and F-16s to fly at low altitudes, at night, and in poor weather to attack ground targets. In addition, the optics in LANTIRN pods have been used to provide surveillance support for ground forces. The LANTIRN system is due to be superseded by the Laser Infrared Targeting and Navigating (LITENING) and Sniper eXtended Range (XR) advanced targeting pods (ATPs).

Pre-BRAC, the USAF had an inventory of 468 targeting pods worldwide, 313 of which were allocated to CONUS units. Post-BRAC, the CONUS-wide allocation will be 298 targeting pods, with 46 in backup inventory. For the NAV pod, the USAF had a worldwide pre-BRAC inventory of 325 pods, 238 of them allocated to CONUS units. Post-BRAC, the CONUS-wide allocation will be 184 navigation pods, with 81 in backup inventory.[4]

Post-BRAC, LANTIRN pods will be used in 16 locations, eight active and eight ANG units; Table 5.6 and Figure 5.3 present further details regarding this set of locations. Of these 16 locations, ten are full users of the pods and six use the LANTIRN for training only. For the training-only units, we modeled demand as that resulting from a training schedule of 20 flying hours per month per PAA.[5] For other units, we assumed a schedule of 17 hours per aircraft per month based on RAMPOD data for ACC and ANG units.[6] Currently, Tulsa ANG (Oklahoma) is a CIRF for ANG units, and Shaw AFB training is supported by a CIRF at Seymour-Johnson AFB. According to the BRAC Report recommendations, Hill AFB is designated as a LANTIRN

---

4 BRAC LANTIRN Pod Redistribution Plan 25 May 05.xls, RAMPOD data, provided by Florencio Garza, ACC/A4MA, September 16, 2005.

5 Personal communication, Jeffrey P. Coddington, HQ ACC/A4MA, via email, January 6, 2006. Note that only 24 PAA at Luke AFB use LANTIRN (out of Luke AFB's post-BRAC total of 76).

6 "AN/AAQ-14 Reliability Metrics (MTBM, MTBF) Wing Summary Grouped by Command, 28 May 1997 to 12 Jan 2004," RAMPOD data, provided by Florencio Garza, ACC/LGMA, January 18, 2004.

Table 5.6
Post-BRAC LANTIRN Operating Locations

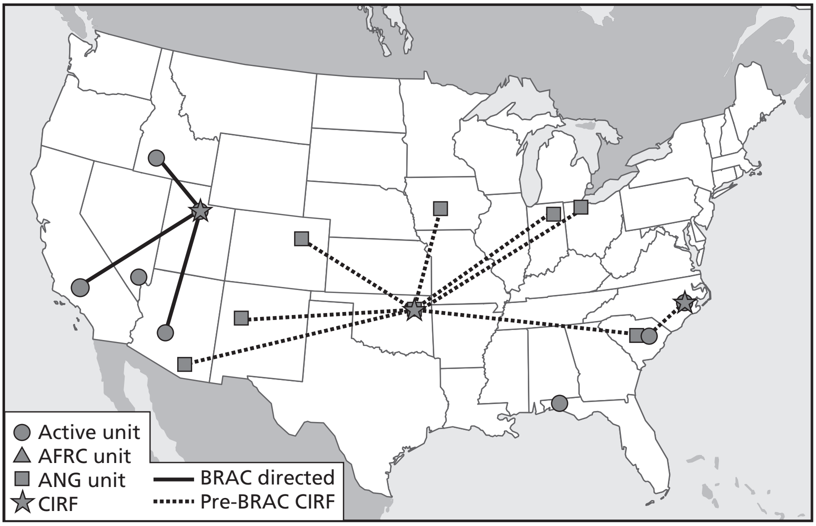
Base Name	MAJCOM	NAV Pods	TGT Pods
Edwards AFB (California)	AFMC	5	4
Eglin AFB (Florida)	AFMC	9	9
Luke AFB (Arizona)[a]	AETC	0	35
Hill AFB (Utah)	ACC	0	53
Mountain Home AFB (Idaho)	ACC	51	34
Nellis AFB (Nevada)	ACC	19	28
Seymour-Johnson AFB (North Carolina)	ACC	95	77
Shaw AFB (South Carolina)[a]	ACC	0	6
Des Moines ANG (Iowa)	ANG	0	0
Kirtland ANG (New Mexico)	ANG	0	0
Toledo ANG (Ohio)	ANG	0	15
Tulsa ANG (Oklahoma)	ANG	0	34
Buckley ANG (Colorado)[a]	ANG	0	0
Fort Wayne ANG (Indiana)[a]	ANG	0	0
McEntire ANG (South Carolina)[a]	ANG	0	0
Tucson ANG (Arizona)[a]	ANG	0	0

NOTE: An additional five NAV pods and three TGT pods are at Sheppard AFB to support maintenance training.

[a] LANTIRN for training only.

CIRF for Mountain Home, Edwards, and Luke AFBs. Two bases are not part of the CIRF network: Nellis and Eglin. Among the CONUS ACC and ANG bases, there are 12 LIATE (LANTIRN intermediate ATE) and LMSS (LANTIRN mobility shelter set) test sets for LANTIRN ILM.

Figure 5.3
Post-BRAC Network, LANTIRN



RAND *MG418-5.3*

Concept of Operations

TGT pods that fail on-wing BIT checks are sent to the LANTIRN ILM facility. For a NAV pod failure, the faulty LRUs are replaced on the flightline, and the removed LRUs are sent to the ILM facility. If the ILM facility is an off-site CIRF, TGT pods are shipped using an air-ride tractor-trailer with CSS,[7] and NAV pod LRUs are sent using express shipping under the SDDC Domestic Small Package Express Blanket Purchase Agreements under two-day air (with a third day allotted for processing). Transit times for TGT pods are obtained using DoD Standard Transit Times—Truckload (U.S. DoD, 2006), and costs are from the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004) (see Table 5.7). The deployment scenario

[7] Note that CSS is not required for LANTIRN TGT pods. However, our inclusion of the unneeded CSS does not significantly increase the relatively small transportation costs for the CIRF networks under consideration (the additional cost is less than $0.1 million in all instances).

Table 5.7
CONUS LANTIRN Pod Transport Costs

Distance Traveled (miles)	$ per Mile
1 to 500	1.69
501 to 1,000	1.88
1,001 to 1,500	1.77
>1,500	1.69

SOURCE: HQ USAF, 2004.

involves the sustained deployment of 20 percent of the combat-coded CONUS PAA. For OCONUS operating locations, ILM is performed at an off-site OCONUS CIRF for which round-trip transit time is assumed to be 15 days for both TGT pods and NAV LRUs.

Using the flying hour program and failure rate factors derived from the RAMPOD database, we determined the failure rate at each location. Repair times for TGT pods were also taken from RAMPOD. For NAV pod LRUs, LRU failure rates were defined as a fraction of overall pod failures, and LRU repair times were derived from data received from Seymour-Johnson AFB (Garza, 2005). The test stations were then allocated so that repair requirements at each location were met. A maximum utilization of 80 percent was assumed for LANTIRN test stands to limit the number of pods in AWM status. Each LANTIRN test station has a crew requirement of two personnel per shift, each pair of crews has a crew chief, and an additional 10 percent is allocated for overhead, so manning is assumed to be 5.5 per test station.

Results

The BRAC-directed establishment of a CIRF at Hill AFB leads to the cost and performance effects in Table 5.8. This CIRF allows for the reduction of two CONUS LANTIRN test stations, along with their associated manpower, while increasing transportation costs by $100,000 per year, for a net reduction of $500,000 annually. How-

Table 5.8
Cost and Performance for LANTIRN BRAC-Directed CIRF Network

	Current	BRAC Directed
Maintenance locations (CONUS/OCONUS)	8/1	5/1
Transportation ($M)	0.1	0.2
Mean transport pipeline		
CONUS TGT pods	4.5	7.6
OCONUS TGT pods	5.1	5.1
CONUS NAV pod LRUs	0.0	2.4
OCONUS NAV pod LRUs	15.9	15.9
Test sets		
CONUS	10	8
OCONUS	3	3
Payroll ($M)	4.3	3.7
Manning		
CONUS	55	44
OCONUS	17	17
Total ($M)	4.4	3.9

ever, shipments to CIRFs lead to an estimated increase of 3.1 INT TGT pods and 2.4 INT NAV LRUs. Given the number of spare pods and LRUs available in the system (including the backup inventories), this INT pipeline increase would not likely have a large operational impact.

Eglin and Nellis AFBs are included neither in a BRAC-directed LANTIRN CIRF nor a pre-existing LANTIRN CIRF arrangement. Because Eglin and Nellis are low-demand locations, each is assigned a single LANTIRN test station that has very low utilization. An alternative is to include Eglin AFB at the pre-existing Seymour-Johnson AFB LANTIRN CIRF while assigning Nellis AFB LANTIRN maintenance responsibility to the BRAC-directed CIRF at Hill AFB. Under this alternative, the expected system cost and performance are as presented in Table 5.9.

Including Eglin and Nellis AFBs in the LANTIRN CIRF network reduces the total test station requirement by one, reducing manpower by $0.3 million per year. Transportation costs increase by approximately $0.1 million per year, for a net annual savings of about $0.2 million. The expected INT pipelines associated with this alternative CIRF network are not significantly different from those of the BRAC-directed network.

Table 5.9
Cost and Performance for LANTIRN CIRF Networks

	BRAC Directed	Alternative
Maintenance locations (CONUS/OCONUS)	5/1	3/1
Transportation ($M)	0.2	0.3
Mean transport pipeline		
CONUS TGT pods	7.6	8.1
OCONUS TGT pods	5.1	5.1
CONUS NAV pod LRUs	2.4	3.3
OCONUS NAV pod LRUs	15.9	15.9
Test sets		
CONUS	8	7
OCONUS	3	3
Payroll ($M)	3.7	3.4
Manning		
CONUS	44	39
OCONUS	17	17
Total ($M)	3.9	3.7

OCONUS Manning Issues

As with the F-15 avionics analysis, the LANTIRN OCONUS CIRF manning requirements exceed the deployment burden for full-time CONUS personnel that can be supported using the AEF rotation concepts. Based on the expected maintenance demands, 17 OCONUS and 44 CONUS full-time maintainers are required under the BRAC Report recommendations. Compared to the total requirement, the OCONUS manning requirements for LANTIRN are disproportionately large. An AEF deployment of 17 maintainers could be accomplished using a workforce of 85 full-time maintainers so that one out of five is deployed to the OCONUS CIRF at any time. This would enable the full-time workforce to man the AEF deployment requirement, but would leave the CONUS ILM locations with underutilized manpower. Another alternative is to use part-time reserve component personnel to fill OCONUS CIRF rotation positions. For example, minimizing the full-time personnel requirement would lead to 44 full-time maintainers in CONUS, with another 11 full-time maintainers OCONUS as part of their AEF rotation. To fill the remaining OCONUS requirement, six part-time maintainers could be activated for an OCONUS CIRF deployment. This would require 60 part-time reserve maintainers, each called up once every two AEF cycles to support the scenario's 20 percent deployment of combat-coded aircraft. Any manning level between these two extremes of 55 and 85 full-time maintainers, with the remainder of the OCONUS requirement filled by activated reserve component maintainers, can be implemented based on other considerations, such as personnel needs, PCS rotations, or budgetary restrictions. Table 5.10 presents the manpower and payroll requirements associated with these two extremes of the policy spectrum. As indicated, six of the personnel listed for full-time OCONUS manning are also counted under part-time CONUS manning when activated part-time personnel are used to manage the deployment burden. Under such a policy, activated part-time personnel would incur both their part-time manning cost and the associated full-time manning cost, since these activated positions would be constantly maintained by rotation of part-time personnel.

Table 5.10
LANTIRN Manning Requirements for Two OCONUS CIRF Staffing Policies, BRAC-Directed CIRF Network

	All Full-Time Personnel	Maximum Use of Part-Time Personnel
Manning		
CONUS full-time	68	44
CONUS part-time	0	60
OCONUS full-time	17	17[a]
Payroll ($M)	5.1	4.6

[a] Six of the 17 are also counted under CONUS full-time manning when activated part-time personnel are used to manage the deployment burden.

Other Considerations

An overarching consideration for all the analyses presented in Chapters Three, Four, and Five is that the move to a centralized ILM structure will create an additional workload to prepare CIRFed commodities, such as engines and pods, for shipping and receiving. Table 5.11 shows the annual total number of receipts at the CIRFs associated with each of the alternative solutions we have presented, under the 20 percent deployment scenario. Note that for some commodities for which CONUS CIRFs support OCONUS FOLs (e.g., TF34), the receipts from OCONUS units are included in the CONUS CIRF count. Note also that no shipping requirement is incurred for commodities whose operating location is colocated with a CIRF (e.g., TF34 engines emanating from Davis-Monthan AFB). Because these CONUS values are systemwide totals, these workloads would be divided among the multiple CONUS CIRFs in each alternative network.

Of course, shipping, preparation, and receipt of CIRF commodities also constitute an additional workload at CONUS CIRFed units. As we discussed in Chapter Three, much of this workload for engines at CIRFed units could be accomplished via dispatch teams at

Table 5.11
Annual CIRF Receipts for Alternative Networks

	CONUS CIRFs	OCONUS CIRFs
TF34	176	0
F110	475	180
F100	719	348
ALQ-184	1,415	2,285
ALQ-131	148	322
LANTIRN TGT pods	229	124
LANTIRN NAV LRUs	198	387
F-15 avionics	4,878	4,811

reserve component units; and the additional workload would generally not be very large at CIRFed active component units, even if retained task teams are not used. For pods and avionics, these dispatch team and retained task team concepts were not applied to CIRFed units, which eliminates this potential source of manpower. For the ALQ-131, the expected annual shipping/receiving workload ranges from 45 pods at Buckley ANG and at Burlington ANG to 58 pods at Davis-Monthan AFB. For the ALQ-184, the expected annual shipping/receiving workload ranges from 70 pods at Duluth ANG to 215 pods at Moody AFB (no other CIRFed location would require more than 105 annual ALQ-184 shipments). Assuming one man-day for pod shipping preparation at the base, and one man-day for receipt of pods from the CIRF, the expected annual workload is between 90 and 116 man-days (approximately 0.35 and 0.45 man-year) for CIRFed ALQ-131 units. Excluding Moody AFB (which would require 430 man-days, or approximately 1.65 man-years), the CIRFed ALQ-184 units would observe an expected annual workload between 140 and 210 man-days (approximately 0.54 and 0.81 man-year). Thus, these additional ECM pod workloads would not be expected to be very large at any individual unit, with the possible exception of ALQ-184 at Moody AFB.

For LANTIRN, TGT pod shipments could be expected to be similar to the relatively small ALQ-131 shipping/receiving workloads. For LANTIRN NAV LRUs and F-15 avionics LRUs, the per-LRU shipping preparation and receipt time would likely be rather short compared with the associated times for engines and pods. Given the relatively small number of LANTIRN NAV LRUs, this would not likely generate a large shipping/receiving workload. For F-15 avionics LRUs, the six CIRFed units all have a comparable PAA (between 15 and 20 aircraft), so one would expect each unit to have a comparable number of LRU shipments—approximately 800 per year (roughly one-sixth of the CONUS total). If the LRU shipping preparation and receipt times are each assumed to require two man-hours, the annual shipping/receiving workloads associated with F-15 avionics LRUs at each base will have an expected value of 3,200 man-hours (approximately 1.54 man-years). This additional workload, while not insignificant, is likely not large enough to render the CONUS CIRF policy ineffective for F-15 avionics.

CHAPTER SIX

Findings, Recommendations, and Concluding Comments

In the course of this research project, we developed new tools for modeling CIRF networks, commodity-specific input factors, and detailed tasking scenarios; conducted network analyses on post-BRAC force structure bed-downs for the CONUS F-15, F-16, and A-10 fleets; and generated and evaluated CONUS CIRF network configurations for aircraft engines, EW pods, LANTIRN pods, and F-15 avionics LRUs. This chapter summarizes both the general and specific findings arising from this work. Recommendations are included with the findings, and the chapter ends with concluding comments.

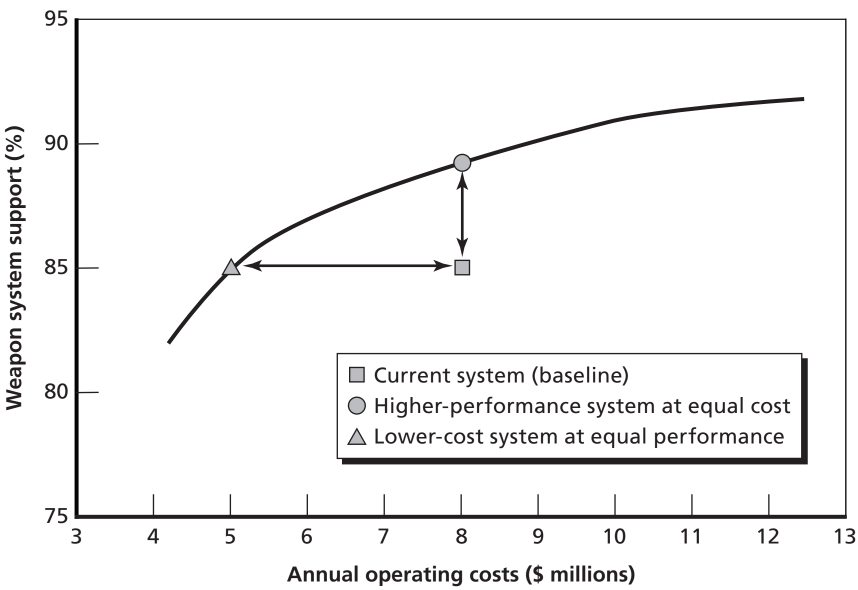
General Findings

The study led us to some general findings that we consider valid for a broad range of alternative force structures, bed-down assignments, and tasking scenarios. Additionally, we think these findings on the characteristics of well-designed CONUS CIRF networks are robust enough to extend to other commodities and other aircraft types as well.

1. CONUS CIRF is a cost-effective maintenance strategy. For most scenarios and commodities examined, the CONUS CIRF concept was found to be a cost-effective maintenance strategy because these centralized ILM networks outperform the traditional USAF policy of fully decentralized ILM networks. The only exceptions were related to the F-15 avionics, in which a shortage of critical LRUs led to degraded system performance under centralized maintenance (although at a significantly reduced cost). Even though the 2005 BRAC Report man-dates the use of CIRFs for many CONUS fighter units' ILM shops, moving to even greater use of CONUS CIRFs can achieve levels of weapon system support comparable to or better than those achieved by the BRAC-directed maintenance network—while achieving significant reductions in total system cost (e.g., 20 percent for the F110) and full-time manpower requirements (e.g., 37 percent for the F110).[1] This idea is graphically demonstrated in the notional, but representative, results presented in Figure 6.1.

The gray square in Figure 6.1 denotes the operating cost and weapon system support performance of a typical decentralized operation, with local ILM facilities at each aircraft operating location. The

Figure 6.1
Notional Results of a Typical CONUS CIRF Commodity Analysis



RAND *MG418-6.1*

---

1 To the extent that total manning requirements (both full- and part-time) are driven by MRC scenario requirements, increased use of CONUS CIRFs allows for reduced use of full-time manpower positions, although increased part-time positions may be needed as an offset to support the total manning requirements.

curve represents the set of efficient network configurations identified through the Q-METRIC analysis procedure. Possible network designs range from low-cost, low-performing configurations (toward the left side of the curve), which generally involve highly centralized networks with highly utilized maintenance facilities, to high-cost, high-performing configurations (toward the right side of the curve), which generally involve decentralized maintenance networks with high maintenance capacity and low utilization. Note that in graphical terms, the gray square falls below the curve. This implies that a management decision to implement a CONUS CIRF network could move cost and performance to, for example, a position represented by the gray circle. This would be a network equal in cost to the current decentralized system but with higher performance.

Alternatively, management might decide to implement a CONUS CIRF network represented by the gray triangle. This is a network with equivalent performance to the current system but significantly lower annual operating costs. Management is of course free to choose any point along the curve, and each of those points is more cost-effective than the current system—i.e., the current, decentralized system is dominated by the set of CONUS CIRF alternatives, all of which are more cost-effective than the current operation. In summary, centralized maintenance networks are generally more cost-effective than the current system of decentralized ILM operations.

2. Potential manpower cost savings more than offset increased transport costs. Why do well-designed centralized networks tend to dominate decentralized maintenance operations? The basic explanation is that CIRF solutions tend to substitute relatively inexpensive transportation costs for relatively expensive maintenance manpower. While it can cost thousands of dollars to transship an aircraft engine or pod to and from a CIRF facility, the costs of these relatively infrequent shipments are more than offset by the reductions in maintenance manpower costs that occur in the CIRF networks. These maintenance manpower reductions are possible because of the improved economies of scale and better manpower utilization that can be achieved in the larger CIRF operations.

3. CONUS CIRF total pipeline requirements generally are not excessive. It is certain that transshipment of reparable and serviceable assets between operating locations and CIRF repair facilities will generate new transport pipelines that absorb available spares assets. Our analyses carefully included all such transport pipeline requirements, and we were careful to assume conservative transit times. In addition, our assumptions did not include procurement of additional assets (e.g., engines or pods) to fill these pipelines. Nevertheless, pipeline asset requirements do not pose a problem in most implementation scenarios, for two basic reasons. First, in most cases the volume of these shipments is relatively small and the CONUS transit time is not long, so the number of assets expected to be INT at any point in time is not very large. Second, compared with the comparable decentralized network, a well-designed CIRF network significantly reduces the total expected number of AWM assets; the consequent reduction in total AWM pipeline can counterbalance—or even outweigh—the new transport pipeline requirements. Note that for centralized F-15 avionics maintenance, no reduction in AWM assets was identified, so the transport pipelines necessarily caused poorer performance under a CIRF network (although at reduced total cost).

4. Many network designs are virtually equivalent in cost and performance. For each commodity and scenario we studied, we found that many alternative CONUS CIRF network designs can be developed that differ only slightly in cost and performance. In other words, the specific situation often permits a great deal of flexibility in the choice of network to implement. Alternative designs can be chosen, for whatever reason, that are only slightly less cost-effective than those forming the efficiency frontier. One potential criterion for selecting between similarly performing network designs is the robustness of a system's performance to unplanned disruptions (e.g., loss of a transportation link). While such an analysis was beyond the scope of our study, it could provide an area of future research for Air Force logistics system analysis.

5. Large user bases are naturally attractive CONUS CIRF locations. Although our analyses generated many different CONUS CIRF network designs, some general patterns emerged. The most dominant pattern to emerge is that large operating locations—i.e., those with large users of a commodity—are prime candidates for a CONUS CIRF location when all other variables are held constant. By colocating the CIRF at the site of a large user, a relatively large transport pipeline segment is eliminated, which significantly reduces the quantity of spare assets in the transshipment pipeline. Thus, colocating the CIRF at a large user site (rather than at a small user site or a location, such as a depot, that has no using unit) makes a larger contribution to performance with smaller costs. Not surprisingly, the most cost-effective CONUS CIRF networks entail colocating the CIRF facilities at large user sites. An important note here is that this was not a ground rule of the analysis, but, rather, the outcome of a neutral optimization procedure that objectively considered all alternative locations.

Specific Findings

In addition to our general findings about the characteristics of well-designed CONUS CIRF networks, we arrived at some commodity-specific findings that bear on CONUS CIRF implementation policies.

1. Spare engine pools are sufficient to support CONUS CIRF pipelines. Our analyses of TF34, F100, and F110 aircraft engines indicate that sufficient spare engine assets exist to adequately support the pipeline requirements needed to implement the CONUS CIRF concept. This is particularly so in the case of the TF34. In addition, significant reductions to the expected number of AWM engines can be achieved via use of CIRFs, actually reducing current spare engine shortages. For the F100 and F110 engines, our CONUS CIRF planning scenarios recognized the reduced fleet sizes planned for the F-15 and F-16. Our calculations demonstrated that existing installed and spare engines, when properly modified, will be sufficient to support CONUS CIRF implementation for these aircraft.

2. CONUS engine retained tasks are not cost-effective. Maintenance planners are considering the inclusion of retained tasks as part of the CONUS CIRF CONOPS for F100 and F110 engines. This policy would allow operating bases that lose full JEIM capability to retain a small ILM capability, sufficient to deal with a small subset of relatively quick and easy maintenance actions. This policy would prevent the transshipment of an entire engine to and from a CIRF for a relatively minor maintenance action. While this idea is intuitively appealing, we recommend against it. We included a CONUS retained task option in our analyses, and our results indicate that retained tasks are not cost-effective. We found that networks operating with retained task teams at aircraft operating locations cost more at equal levels of performance or, alternatively stated, perform more poorly at equal levels of cost.

3. F-15 avionics ATE assets cannot support base-level BCS screening. A similar policy issue exists with F-15 avionics. A significant fraction of the F-15 avionics LRUs removed at the flightline and sent to the local ILM facility are found to be BCS when tested on ATE. In other words, the tested LRU is found to have no fault and is simply returned to the serviceable inventory. Some maintenance planners think that in the CONUS CIRF implementation plan, F-15 units losing full ILM capability should maintain the capability to screen LRUs for this BCS condition before they are sent to the CIRF, thus eliminating unneeded transportation costs and pipeline delay times. In fact, this is how F-16 avionics LRUs are processed today. As was the case with the engine retained tasks policy, this policy seems appealing, but we recommend against it. We have conducted F-15 avionics LRU analyses with and without local screening for BCS conditions, and we found that the USAF inventory does not have sufficient ATE assets to support the BCS screening policy.

BCS screening and engine retained tasks are significantly different in one important respect: engine retained tasks are a clearly defined set of maintenance actions, and it is fairly obvious which engines would be repaired locally and which would be sent to the CIRF. Thus, the "retained task list" simply partitions the total work into a local fraction and a CIRF fraction. With avionics LRUs, however, the situation is quite different. To find the fraction of LRUs that are BCS, all LRUs must be tested. The test station time required to screen the LRU is a significant fraction of the total time it would take to repair the LRU if it proved to be necessary; and when the LRU fails the BCS screen and is sent to the CIRF, this testing must be repeated. BCS screening thus can create a significant increase in the total system maintenance workload.

Whether the BCS screening policy is cost-effective or not depends on the situation—specifically, on the relative frequency of BCS events and the ratio of screening time to repair time. Our analysis of historical F-15 maintenance data indicates that even though BCS screening would be expected to very slightly increase the availability of serviceable F-15 avionics LRUs at the operating bases (by a total of less than one critical LRU systemwide, for our deployment scenario), the screening policy is not cost-effective. Further, for the units under consideration, the inventory of certain ATE assets to support this concept is insufficient.[2]

4. F-15 avionics LRU spares pools are problematic. In most of our detailed CONUS CIRF analyses, we present CONUS CIRF network designs that produce weapon system performance levels equivalent to those of the decentralized option at a significantly lower total system cost. In the case of F-15 avionics LRUs, however, this is not the case. Many F-15 avionics LRUs are in critically short supply, and any increased pipelines implied by CONUS CIRF implementation can be expected to increase the back-order situations for these assets. Note that our analysis did not attempt to identify any potential reduction in AWM assets resulting from centralization for these LRUs. In our detailed analyses, we attempted to estimate the impact of these critical items on F-15 support, and we determined, for example, that centralization to an alternative CONUS CIRF network having five ILM facilities could be expected to add an average of three critical LRUs to the CONUS transport pipeline.

5. CONUS CIRF network performance is sensitive to assumed removal rates and repair times. Our analyses determined that the ALQ-131 and ALQ-184 EW pods are good candidates for CONUS CIRF implementation. However, we recognize that there is a higher

---

[2] Note that the ATE asset in question, TISS, is currently undergoing a modernization program. The Air Force decided against a new procurement because of obsolescence issues, which made such procurement prohibitively expensive.

level of uncertainty in the results for these commodities because estimates of their wartime failure rates vary widely.[3] In one sense, this issue concerns the feasibility of OCONUS CIRF support for deployed units more than it does the feasibility of CONUS CIRF support. Nevertheless, our CONUS CIRF scenarios incorporate MRC and AEF taskings and support relationships, which means that wartime failure rates are important planning factors in our CONUS CIRF analyses. To the extent that a CONUS CIRF implementation represents a drawdown in total maintenance assets, an understanding of the likely wartime demand on these assets becomes increasingly important. We therefore recommend that additional study be performed, drawing on data from current operations in Iraq and Afghanistan, to establish reliable wartime rates and factors for these assets.

In the case of aircraft engines, the standard repair times reported in the PRS or LCOM data systems are often significantly shorter than the engine repair times that are reported in CEMS, even after subtracting AWM and AWP times from CEMS. CONUS CIRF maintenance manpower requirements implied by the CEMS estimate are much higher than those derived from PRS- or LCOM-based repair time estimates. Therefore, we recommend that these repair time differences be fully reconciled as part of a CONUS CIRF implementation.

Concluding Comments

The overall results of this project provide strong support for the feasibility and desirability of CONUS CIRF networks as a cost-effective maintenance policy that is capable of providing improved support to USAF warfighting forces with reduced levels of manpower and lower total operating costs. We think the CONUS CIRF concept holds great promise as the USAF continues to modernize and transform itself to provide agile combat support to the AEF.

---

[3] This is a recognized difficulty for ECM pods (see Feinberg et al., 2002; also Mills and Feinberg, 2001).

APPENDIX A

Technical Description of Q-METRIC Modeling Tools

Analyses of CIRF networks via the Q-METRIC approach were accomplished by iteratively applying the Facility Location Designator and the Pipeline Performance Evaluator tools as described in this appendix.

Facility Location Designator

This section presents a simplified overview of the Facility Location Designator model. Define the following sets:

$$i \in I \text{ bases}$$

$$j \in J;\ I \subseteq J \text{ potential repair facilities.}$$

Note that set J may include both bases and non-base maintenance facilities. This MILP model has a set of binary decision variables:

$$x_{ij} = \begin{cases} 1 & \text{if base } i \text{ has its ILM performed at CIRF } j \\ 0 & \text{otherwise.} \end{cases}$$

Note that $x_{ii} = 1$ implies that base i has its ILM performed on site. Note also that the terms *CIRF* and *repair facility* are used interchangeably in this context.

Maintenance capacity is modeled using a notional *repair machine*. For avionics and pods, this repair machine represents a test stand; for engines, two distinct types of repair machines are necessary, one representing engine rail teams and another representing engine test cells. The capacity decision at each CIRF is modeled using the integer variable M_j, which is the number of repair machines operating at CIRF *j*. Define the following data parameters:

λ_i	failure rate at base *i*
μ	repair rate
r_i	expected number of INW commodities from base *i*; $r_i = \lambda_i / \mu$
τ_{ij}	one-way transit time between base *i* and CIRF *j*
δ_{ij}	mean total transportation cost (over a unit time) to ship base *i*'s repair to CIRF *j*
A	upper bound on total maintenance manpower
B	upper bound on total number of repair machines
v	total number of bases.

Note that r_i does not include components in queue; this is the mean value of the number of components in service at any point in time.

We identified the existence of significant scale economies in ILM manpower via LCOM analyses; this rules out the use of a simple linear model. Since M_j has been restricted to integer values, piecewise-linear functions can be used to capture the nonlinearities in manpower requirements occurring from scale economies. These piecewise-linear functions can be fitted to the results of the scale economy analyses to obtain the manpower requirements per repair machine. In a similar manner, operating cost functions can be created to reflect the personnel costs associated with this manpower requirement, along with any facility expansion costs required to add capability at a CIRF (e.g., purchase of additional engine test cells). Define the following piecewise-linear functions:

$\Gamma_j\left(M_j\right)$	manpower requirement to operate M_j repair machines at CIRF *j*

$\Phi_j\left(M_j\right)$ operating cost to maintain M_j repair machines at CIRF *j*.

The objective function, minimizing total operating costs, may be written as

$$\sum_j \left[\Phi_j\left(M_j\right) + \sum_i \delta_{ij} x_{ij}\right] \tag{A.1}$$

Constraint (A.2) is a simple assignment constraint, requiring every base to assign its repair to a unique CIRF. Constraint (A.3) ensures that base *i* does not perform ILM for another base if base *i* does not perform its own ILM:

$$\sum_j x_{ij} = 1 \quad \forall i \tag{A.2}$$

$$\sum_{k \in I} x_{ki} \leq v x_{ii} \quad \forall i \tag{A.3}$$

Constraints are included to limit the total manpower (A.4) and number of repair machines (A.5):

$$\sum_j \Gamma_j\left(M_j\right) \leq A \tag{A.4}$$

$$\sum_j M_j \leq B \tag{A.5}$$

To incorporate the effects of finite maintenance capacity limitations in the model, select a value for the parameter $\hat{\rho}$, maximum allowable utilization for any repair machine; $0 \leq \hat{\rho} < 1$. The choice of a specific $\hat{\rho}$ value is discussed in detail later in this appendix.

Constraint (A.6) limits repair machine utilization at each CIRF:

$$\sum_i r_i x_{ij} \le \hat{\rho} M_j \quad \forall j \tag{A.6}$$

It is necessary to estimate the mean total number of unserviceable components in the pipeline, including those INT between a base and a repair facility, those INW at the repair facility, and those in the queue at the repair facility (AWP commodities are assumed to be unaffected by ILM structure and thus are removed from the available pool of spares at the beginning of the analysis). Assuming an unconstrained number of transport vehicles, the mean number of unserviceable components INT and INW at the repair facility can be easily computed if the failure rate and service rate are known, independent of either the failure or service time distributions. However, because of nonlinear stochastic queueing effects, computing the number of AWM components at the repair facility is somewhat more difficult. For certain distributions (Poisson failure rate and exponential service times are one example), the number in queue can be computed if both the number of servers (repair machines) and server utilization are known. Thus, given server utilization ρ, the following function, piecewise-linear with respect to the number of servers, can be computed a priori:

$$\Theta\left(M_j, \rho\right),$$

which is the mean number of commodities INW and in queue at CIRF j having M_j repair machines, each operating at a utilization of ρ.

For any base that performs solely its own ILM operations, the exact server utilization is known a priori for any number of machines. However, for CIRF operations, server utilization also depends on the assignment of bases to the CIRF. Thus, some estimate of CIRF server utilization is needed. Recall that a maximum allowable utilization $\hat{\rho}$ has been assumed for every repair machine. Because of the structure of the objective (minimize a cost function that is strictly increasing with respect to the number of repair machines), for any assignment of bases to repair facilities, the math program will attempt to minimize the number of repair machines used, which is equivalent to maximizing server utilizations. Assuming that each repair machine located at a CIRF is operated at its maximum allowable utilization, $\hat{\rho}$, provides an upper bound on the number of commodities in the pipeline, because of the structure of function

$$\Theta\left(M_j, \rho\right),$$

which is strictly increasing with respect to ρ. To incorporate these pipeline effects in the model, select a value for the parameter F, which is an upper bound on the estimated number of unserviceable commodities. The choice of a specific F value is discussed in further detail later in this appendix.

Constraint (A.7) places an upper bound on the mean number of components in the total pipeline:

$$\sum_j \left[\Theta\left(M_j, \hat{\rho}\right) + \sum_i 2\lambda_i \tau_{ij} x_{ij}\right] \leq F. \tag{A.7}$$

Because the pipeline computation in constraint (A.7) uses an approximation for the components INW and in queue at a CIRF, a two-stage algorithm is needed that more accurately measures the pipeline effects. In stage one, the Facility Location Designator optimization model is solved to obtain an assignment of bases to repair facilities and a sizing of repair facilities. In stage two, the network obtained in stage one is evaluated in a manner that more accurately reflects the pipeline effects. Within stage two, a marginal analysis may be performed to determine an "optimal" assignment from a pool of spare components to the base-repair facility network. An algorithm derived from the METRIC family of inventory models is used for this stage-two computation. This stage-two algorithm is presented in the following section.

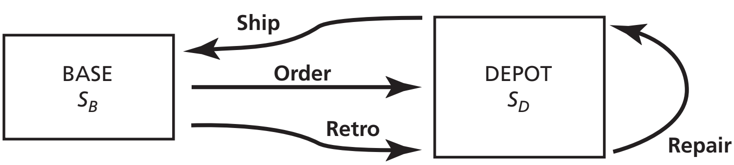
Pipeline Performance Evaluator

Sherbrooke (1968) developed the METRIC algorithm to model a base-repair depot supply system and to determine base and depot stock levels for a group of recoverable items. For illustrative purposes, consider a simple system, with one base and one repair depot. Note that in this section we use the conventional METRIC terminology, referring to the maintenance facility as a "depot," rather than a "CIRF"; the logic follows identically in either case. METRIC uses the following decision variables:

S_D number of spare components authorized at the depot
S_B number of spare components authorized at the base.

Figure A.1 gives an overview of the basic logic to the METRIC algorithm. Failures are assumed to occur at the base according to a Poisson process, at which time an order is placed at the depot; it is generally assumed that the depot receives this order instantly. It is also assumed

Figure A.1
METRIC Logic



With Poisson order process and infinite service, we invoke Palm's theorem:

1. Depot pipeline is Poisson with mean = **order** rate × (**retro** time + **repair** time)
2. Depot back-orders are a function of S_D
3. Depot delay time = *DDT* = depot back-orders/**order** rate
4. Base pipeline is Poisson with mean = order rate × (**order** and **ship** time + DDT)
5. Base back-orders are a function of S_B
6. Use marginal analysis to optimally allocate S_B and S_D, etc.

RAND *MG418-A.1*

that the number of transport providers is unlimited, so the failed component is immediately entered into retrograde transit to the depot. If the depot has an available spare component, it immediately enters this component into shipment to the base. A limitation to the METRIC approach occurs due to its treatment of maintenance at the depot. The depot is assumed to have unconstrained service capacity, in which there is always an idle maintenance line waiting to receive any new inductions. This has a subtle, but important, implication: Every commodity that enters the depot faces the same expected time in the repair process (INW and AWM) *independent of depot workload*. If the unconstrained service assumption is maintained, Palm's theorem may be invoked, allowing the depot pipeline to be modeled as a Poisson random variable, with mean equal to the order rate (i.e., failure rate) multiplied by the sum of retrograde transit time and depot repair time. Then, for any value of S_D, the mean number of depot back-orders (demands unsatisfied because of insufficient stock levels) can be computed using the Poisson probability distribution.

Sherbrooke's key insight was that mean depot delay time (interval between an order's arrival and start of its replacement's shipment) can be computed from mean depot back-orders and order rate. Because the depot pipeline is a Poisson process and an unconstrained transport service exists, the base pipeline can also be modeled as a Poisson random variable, with mean equal to order rate multiplied by the sum of the order and ship time and the depot delay time. In a manner similar to that used for the depot, for any value of S_B, the mean number of base back-orders can be computed using the Poisson probability distribution. The METRIC algorithm then uses marginal analysis to determine near-optimal values of S_D and S_B.

It is important to note that METRIC was developed to compute a spare commodity requirement, so neither the assignment of bases to repair facilities nor the maintenance capacity at repair facilities was treated as a decision within the model. Unfortunately, these are the two primary decisions to be addressed for CONUS CIRF network design. The network design decision can be analyzed via the Facility Location Designator optimization model described in the previous section; such analysis could be performed prior to the METRIC pipeline analysis.

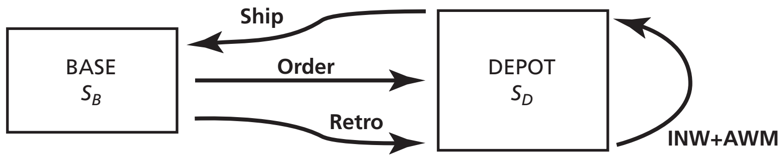
Unfortunately, the "maintenance capacity" weakness of the METRIC algorithm poses a greater challenge for this analysis. The traditional METRIC algorithm assumes unconstrained service at the repair facility, resulting in a repair time that is independent of repair workload. This assumption is flawed in the case of a constrained service capacity, where repair time comprises both an INW time (that can be assumed to be independent of workload) and an AWM time (that is highly dependent on workload). For any fixed and finite repair capacity, the mean time each induction spends AWM increases as the workload at the repair facility increases.

Therefore, a version of METRIC allowing for finite service capacity must be considered. Sleptchenko, van der Heijden, and van Harten (2002) presented a model that incorporates a finite service capacity within the general constructs of the VARI-METRIC algorithm (Slay, 1984). Within our CONUS CIRF analysis, we extended this body of work into a new algorithm named Q-METRIC, which also explicitly considers the queueing effects associated with finite maintenance capability, while incorporating complications germane to this study and outside the scope of Sleptchenko and his colleagues' work (e.g., test stand availability considerations for avionics pods). Q-METRIC analyzes the nonlinear queueing effects associated with stochastic failure and repair, and performs an allocation of spare assets to pipelines in a near-optimal fashion.

Suppose that instead of the unconstrained repair capacity assumed earlier, the depot has c servers (repair machines), with an identical exponential service time distribution at each server. The maintenance process at the depot can then be modeled as an $\left(M / M / c\right)$ queue, which has a known, closed-form probability distribution function (PDF) for the number of commodities INW and in queue.

Figure A.2 provides an overview of the basic logic to the Q-METRIC algorithm. Failures are assumed to occur at the base according to a Poisson process, at which time an order is placed at the depot (this order is received instantly). An unconstrained transport service is assumed, allowing the retrograde service to be modeled as an $\left(M / G / \infty\right)$ queue, which also has a known, closed-form PDF, and the failed component is immediately entered into retrograde transit to

Figure A.2
Q-METRIC Logic



With Poisson order process and finite repair:

1. Use M/M/c model to obtain PDF of quantity INW+AWM
2. Use M/G/∞ to obtain PDF of quantity in retro pipeline
3. Convolute (1) and (2) to obtain PDF of quantity in depot pipeline
4. Depot back-orders are a function of S_D and PDF from (3)
5. *DDT* = depot back-orders/**order** rate
6. Base pipeline is Poisson with mean = order rate × (**ship** time + DDT)
5. Base back-orders are a function of S_B
6. Use marginal analysis to optimally allocate S_B and S_D, etc.

RAND *MG418-A.2*

the depot. If the depot has an available spare component, it also immediately enters this spare component into shipment to the base. The $(M/M/c)$ queueing model is used to obtain the PDF of the number INW and AWM at the depot, and these two PDFs are convoluted to obtain the PDF for the total depot pipeline. Then, for any value of S_D, the mean number of depot back-orders can be computed using the depot pipeline PDF. As before, mean depot delay time can be computed from mean depot back-orders and order rate. Because the output of an $(M/M/c)$ queue follows a Poisson process and an unconstrained transport service exists, the depot pipeline is a Poisson process, allowing the base pipeline to be modeled as a Poisson random variable, with mean equal to order rate multiplied by the sum of the order and ship time and depot delay time. Again, for any value of S_B, the mean number of base back-orders can be computed using the Poisson probability distribution. The Q-METRIC algorithm then uses marginal analysis to determine near-optimal values of S_D and S_B.

These basic versions of the MILP and Q-METRIC models can be expanded to allow for such complicating factors as test-stand down-time (for pods and avionics) and retained tasks at units that relinquish their ILM shops. For engine repair, the series nature of a JEIM must be reflected in separate resources for engine repair (rail teams) and engine testing following repair (test cells). An additional complication for engine repair is that for some engine families (e.g., F100), multiple versions of the engine require dedicated repair resources (rail teams) but can share test cells. These models become much more complex when these additional considerations are included.[1]

Iterative Procedure

In many commercial applications, facility location decisions are modeled without an explicit accounting for the level of system performance. For this study, any increases in efficiency achieved through the implementation of CONUS CIRFs were not to come at the expense of reduced capabilities, measured here as mission capable rates or serviceable spare levels—the support of USAF operations remained the most important goal. When system performance is not a key consideration, a minimal cost solution can often be identified because of the competing effects of transportation costs (which decrease as additional facilities are added, since more storage/production facilities are closer to their markets) and facility operating costs (which increase with increasing number of facilities). The result is the familiar bathtub, or U-shaped, combined cost curve providing a minimal cost solution.

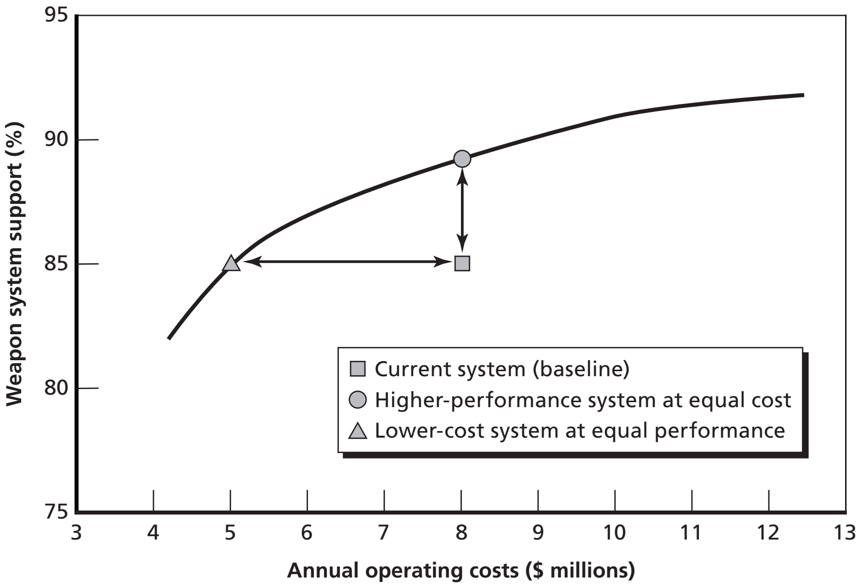
In this analysis, the goal was to identify CONUS CIRF postures that provide the maximum system performance for the minimum total cost. As expenditures are reduced, weapon system availability is necessarily degraded. The two algorithms described above provide a way to determine the extent of these tradeoffs, identifying a set of CONUS CIRF network design solutions that reside on the efficient frontier.

[1] See also Rappold and Van Roo, DOI: 10.1016/J.EJOR.2008.08.006, for which one of the authors of this monograph provided another approach to the study of capacitated repair network design.

Decisionmakers can then see the explicit tradeoffs between cost and system performance.

The two mathematical models presented above operate in an iterative fashion, with the MILP determining a minimum-cost CIRF network, and Q-METRIC evaluating the performance of this network. Given initial, arbitrarily large values for F and $\hat{\rho}$, solve the Facility Location Designator optimization model, and then use the Q-METRIC algorithm to determine the system performance of this network design. Next, decrease F by some predetermined amount, resolve the optimization model, and evaluate the solution using Q-METRIC. Repeat this iteration until F becomes small enough to cause infeasibility; then reset F to its initial value, decrease $\hat{\rho}$ by some predetermined amount, and restart the procedure. The resulting set of solutions can then be examined to determine the set of solutions residing on the efficient frontier, demonstrating the tradeoff between cost and system performance (see Figure A.3). If the cost and performance of the current ILM system are known (denoted by the gray square in the figure), CONUS CIRF networks can be identified that either achieve similar performance to the current network at the minimal cost (denoted by the gray triangle) or that achieve maximum performance at the current cost (denoted by the gray circle). Alternatively, any point lying along this tradeoff curve can be selected as being more cost-effective than the current system.

Figure A.3
Identification of CIRF Networks That Improve Performance and/or Reduce Cost



RAND *MG418-A.3*

APPENDIX B

Assessment Scenarios and Sources of Input Data

This appendix explains the details of the tasking scenarios developed for the CIRF analyses. These flying scenarios are based on post-BRAC aircraft bed-down plans and include peacetime training, AEF rotational deployments, and MRC notional taskings. Also presented are details on the sources and treatment of maintenance and failure rate data that we needed to perform the analyses, as well as transportation data sources for certain commodities.[1]

Tasking Scenarios

There are a large number of alternative ILM network configurations, each defined by an assignment of flying units to repair facilities and a maintenance capacity at each repair facility. A network configuration is evaluated with regard to its ability to support a set of scenarios. One component of such a scenario is the fleet size to be supported. Table B.1 contains the total PAA across all CONUS units that is implied by implementation of the BRAC Report recommendations for the CONUS CIRF commodities of interest. The BRAC Report recommendations establish several CONUS CIRF relationships, which are assumed to be mandatory in these engine and ECM pod analyses even

[1] Because many transportation costs are quoted on a per-mile basis, the road distances between CONUS locations were determined using the distance between base ZIP codes, as computed by Mapquest.

Table B.1
Total Post-BRAC CONUS PAA for CIRF Commodities

CIRF Commodity	CONUS PAA
TF34[a]	270
F110-100[b]	291
F110-129[c]	78
F100-220[c,d]	626
F100-229[c]	75
ALQ-131[e]	126
ALQ-184[e]	498
LANTIRN	554
F-15 avionics[f]	320

SOURCES: BRAC Report; AF/XPPE, FY06PB_Mar05_acftmsls3.xls, AF Program Data System, 2005.

[a] Including 18 PAA at Spangdahlem AB that currently have JEIM performed at Shaw AFB; these PAA must be supported within any future CONUS JEIM network.

[b] Excluding AFMC aircraft at Edwards and Hill AFBs because of units' special engine testing mission.

[c] Excluding aircraft at Edwards AFB because of unit's special engine testing mission.

[d] Assuming all F-15A/B/C/D have converted to use of F100-220 A/E engine.

[e] Excluding units at Nellis AFB, Eglin AFB, and Tucson ANG because they support pod testing requirements.

[f] Excluding units at Nellis AFB (contractor supported) and Edwards AFB (because of unit's special AFMC testing mission).

though additional supported units may potentially be added to BRAC-designated CIRFs.

It is not sufficient to consider only peacetime operations at CONUS units, since the CONUS CIRF network must also be able to support deployed operations. For the purposes of this study, an unclassified notional sizing scenario was developed in which 20 percent of the CONUS combat-coded aircraft deploy to a single unspecified theater, where they perform sustained operations for an indefinite period.[2] In effect, this scenario assumes that 20 percent of combat-coded aircraft will be deployed and operating at all times, so the CIRF network must be able to support this level of operating tempo. This deployment size was selected to be in accordance with the AEF construct, in which one-fifth of combat-coded units are prepared to deploy at any time. Within this notional scenario, deployed aircraft are assumed to operate out of multiple FOLs within the theater, with each FOL hosting a roughly squadron-sized force. It is assumed that each FOL has no ILM capability; rather, all deployed aircraft receive support from a single OCONUS CIRF in theater and/or a CONUS CIRF. If an OCONUS CIRF is used, it is assumed that the additional workload attributable to the deploying aircraft will be accomplished by personnel deploying from the CONUS CIRFs.[3] This scenario assumes that each CONUS unit deploys 20 percent of its combat-coded aircraft.[4] An aircraft flying schedule is necessary to fully define the scenario. Table B.2 contains a notional deployment flying schedule with the average daily flying

Table B.2
Deployment Daily Flying Schedules

	A-10/OA-10	F-15	F-16
Hours/day	2.5	3.0	3.5

---

2 Recall that ILM facilities are intended to support sustained operations; the heavy, short-term demands associated with surge operations are supported via inventory authorizations, e.g., WREs.

3 Note that if a deployment occurs in a theater that currently operates OCONUS CIRFs (e.g., the PACAF F110 CIRF at Misawa AB), the deployment requirement for manpower for such an OCONUS CIRF would be less than that computed in this scenario, because the OCONUS CIRF's existing manpower would be used. The desire to consider a single deployment scenario to an unspecified theater precluded such an analysis.

4 An alternative is to deploy aircraft by squadrons from selected individual units, which would necessitate that many deployment scenarios be created so that the ensuing differences in the structure of the residual CONUS fleet could be examined. The employed scenario was selected in the interest of simplifying the analysis by allowing consideration of only one, consistent scenario.

hours per PAA, by aircraft of interest, assuming seven-day-per-week deployed flying operations.

The residual CONUS aircraft are assumed to continue their peacetime flying schedule. The FY 2005 Programmed Flying Hour Schedule was used to compute a peacetime aircraft flying schedule for each relevant MAJCOM. This flying schedule, defined as the average monthly flying hours per PAA, by aircraft of interest, by MAJCOM, is presented in Table B.3.

Within this analysis, ILM networks are evaluated and selected against this deployment scenario. In all instances, full-time manning is defined as the requirement to support this deployment scenario. An MRC scenario, wherein 50 percent of combat-coded aircraft deploy to one theater and 50 percent deploy to another, is used to determine the requirement for part-time positions associated with the reserve component (ANG/AFRC). Within this larger, MRC scenario, it is assumed that deployed aircraft are supported through an in-theater OCONUS CIRF potentially along with a CONUS CIRF, and that non-combat-coded aircraft maintain their peacetime flying schedule and are supported at a CONUS CIRF. The difference between the manning requirements for the MRC and the 20 percent deployment scenarios

Table B.3
Peacetime Monthly Flying Schedules

MAJCOM	A-10/OA-10	F-15	F-16
ACC	38.20	24.71	24.59
AETC		21.73	24.08
AFMC	10.17	9.51	15.51
ANG	22.20	20.94	22.78
AFRC	22.67		22.05
USAFE[a]	37.68		

SOURCES: AF/XOOTF, FlyingHours.xls, 2004; and AF/XPPE, FY06PB_Mar05_acftmsls3.xls, 2005.

[a] USAFE flying schedule included because of CONUS JEIM responsibility for Spangdahlem AB TF34.

constitutes the part-time manning requirement for each commodity. Note, however, that alternative ILM networks are selected on the basis of performance in the 20 percent deployment scenario. For this analysis, no differentiation was made between different "types" of full-time manpower (e.g., active duty versus ANG).

We assumed that the location where ILM was performed would have no effect on actual repair time for a component. Maintenance time was also assumed to remain unchanged in a deployment. Similarly, AWP rates were assumed to remain constant in CONUS independent of ILM locations. This is a conservative assumption. Centralization of ILM might have some effect on AWP, depending on the underlying cause for AWP. If AWP rates are driven by systemwide shortages of critical items, then the ILM network configuration will have little effect on AWP rates. However, if AWP rates are driven by thinly distributed pools of spares assets at widely dispersed ILM locations, such that one ILM unit suffers an AWP condition for a component while another ILM unit has a serviceable spare of that same component, then consolidation of CONUS ILM units into CIRFs can be expected to improve AWP rates. In the interest of providing conservative estimates of the projected benefits of CIRFs, we used a constant AWP rate for CONUS units. Because of the increased flying schedule associated with deployed operations, we assumed that deployed AWP rates increased proportionately with the increase in operating tempo between peacetime training and deployed operations.

Engine Maintenance Data

Comprehensive Engine Management System

To assess the performance of a CIRF facility and estimate the manpower needed to operate it, the Q-METRIC analysis requires an estimate of the normal repair time for an engine. Historical engine maintenance time experience is captured in the CEMS, which is the centralized USAF standard system for all aspects of jet engine management. CEMS is administered by OC-ALC/LPRC and is documented by Technical Order (TO) 00-25-254-1 (U.S. Air Force, 2001). CEMS is an accounting database intended to provide asset control and physical accountability for assets. In addition, it provides pipeline analysis and life tracking for critical assets. As such, it was used to obtain observed maintenance times for engines. This section outlines the data available in CEMS and how they were used to determine a mean engine repair time, or "service time," for use in the Q-METRIC model.

CEMS records information on an individual engine by serial number. Whenever the status of an uninstalled engine changes, it is updated to CEMS, including engine location and condition. Changes in engine status document the engine's progression from serviceable, to in need of maintenance, to AWM, to INW, to finished maintenance and finally being available for use. CEMS thus tracks the progression of an engine in the pipeline.

In addition, a given engine sent to a JEIM shop may change its status several times before its maintenance is completed. For example, a shop may put an INW engine on hold because parts are back-ordered or to allocate resources toward other engines. This is represented in the CEMS database as a series of individual entries detailing dates and times that an engine changes status among INW, AWM, and AWP. One difficulty that arises when using CEMS data to estimate expected maintenance time is that CEMS does not directly record the time spent performing maintenance. Rather, the INW status code reflects the time during which the engine was available to be worked on. Therefore, the time during which an engine has the INW status does not always identify how long the engine repair took or even that period during which work was being done. For example, an engine entering a maintenance bay near the end of a workweek will retain the INW status over the weekend even if no shifts are scheduled for those days, and that engine's status will not change until maintenance is completed or work stops for some other reason (e.g., because of unavailable parts). In addition, dates and times entered into the database may not be precise, because the emphasis is on recording that changes in status have occurred rather than the exact times at which they occur.

Processing CEMS Data

Within CEMS, an engine is received at the JEIM, is listed as AWM, and has its model and serial number recorded. After maintenance, it will have a number of entries reflecting its transitions between INW, AWP, and AWM status. For each change in status, it has a date and time stamp signifying when it left that status and how long it spent in that status (down to tenths of a day). Figure B.1 shows an example of how a notional engine appears in CEMS. Since the Q-METRIC model needs expected or average total maintenance time, this CEMS transaction status data must be processed to develop an estimate of MTTR for the engine.

In this figure, the "Pipe Code" identifies the INW segments for the particular engine (e.g., A2A in this column indicates that an INW segment was just completed). Also identified are the model and serial number, the date and time each segment ended, the sequence number

Figure B.1
Typical CEMS Engine Status Data

TMSM	SERIAL NUMBER	DATE	TIME	SEQUENCE NO	SRAN	CONDITON CODE	TRIGGER	PIPE CODE	DAY COUNT
TF0034100A	GE00000000	2003102	1400	4771449	4803	RB			0
TF0034100A	GE00000000	2003106	600	4772439	4803	MF	MF		0
TF0034100A	GE00000000	2003106	601	4772449	4803	JF	FB	A1C	0
TF0034100A	GE00000000	2003106	602	4772459	4803	HF	FB	A2A	0
TF0034100A	GE00000000	2003114	600	4775359	4803	JF	FB	A2B	8
TF0034100A	GE00000000	2003115	600	4775959	4803	EF	FB	A2A	1
TF0034100A	GE00000000	2003163	600	6770309	4803	HF	FB	A2C	48
TF0034100A	GE00000000	2003170	600	6772729	4803	JF	FB	A2B	7
TF0034100A	GE00000000	2003170	601	6772739	4803	EF	FB	A2A	0
TF0034100A	GE00000000	2003177	600	6774639	4803	JF	FB	A2C	7
TF0034100A	GE00000000	2003178	600	6775529	4803	EF	FB	A2A	1
TF0034100A	GE00000000	2003183	600	6776959	4803	HF	FB	A2C	5
TF0034100A	GE00000000	2003205	600	7774969	4803	JF	FB	A2B	22
TF0034100A	GE00000000	2003205	605	7774979	4803	EF	FB	A2A	0
TF0034100A	GE00000000	2003212	500	7777489	4803	JF	FB	A2C	7
TF0034100A	GE00000000	2003221	530	8769709	4803	EF	FB	A2A	9
TF0034100A	GE00000000	2003222	805	8770169	4803	HF	FB	A2C	1.1
TF0034100A	GE00000000	2003247	600	8779079	4803	JF	FB	A2B	24.9
TF0034100A	GE00000000	2003260	600	9770989	4803	HF	FB	A2A	13
TF0034100A	GE00000000	2003263	600	9772079	4803	JF	FB	A2B	3
TF0034100A	GE00000000	2003283	600	10770929	4803	FB	FB	A2A	20
TF0034100A	GE00000000	2003296	700	10775899	4803	SB	SB	H1D	13
TF0034100A	GE00000000	2003298	800	10775029	4489	RB	RB	C2A	2

RAND MG418-B.1

and "SRAN" (location of the activity), the condition code, the trigger, and the day count (in the segment just completed). Using this information, the first step is to convert the day count data for INW segments into INW hours. We assumed that a typical JEIM shop is in operation for two eight-hour shifts, five days per week, with additional weekend operations scheduled for ten weekends per year. To convert CEMS status days into elapsed maintenance hours,

1. determine day of the week
2. determine number of days in initial week
3. determine number of full weeks/weekends
4. determine number of days in final week.

A CEMS record includes the date in YYYYDDD format, where DDD is the Julian day of the calendar year. A program was written to convert this day into the day of the week.[5] For each full week, an engine record accumulates 5 * 8 * 2 = 80 hours of work. In addition, we assume there are on average 10/52 * 16 hours of work performed per weekend. Next, we determine the number of days in the initial and final weeks of the segment. We assumed that both the segment start and segment completion dates were each a complete work day and that each complete work day in the start and end weeks accumulated 16 hours of work. Thus, for each segment, the INW days were translated into INW hours, and the INW segments for a given engine from induction to return as serviceable were added to get a total INW time. The CEMS data we used covered September 2001 through December 2003.

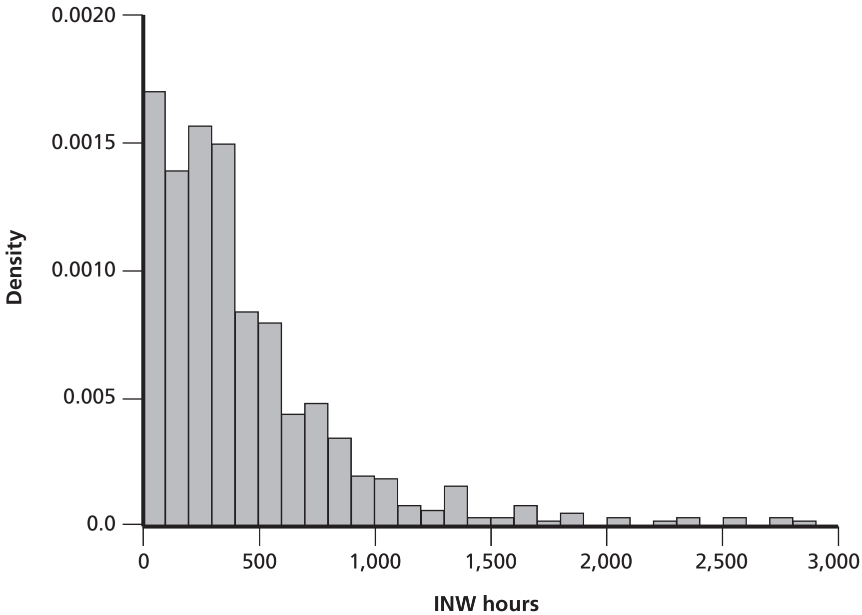
In-Work Time Distribution

The next step in readying the information for use in the Q-METRIC model is to determine a probability distribution that accurately describes the distribution of the observed INW times. For the TF34, we found that actual INW times are distributed as shown in Figure B.2.

---

[5] Year-day was translated to date using "A Date Module" (Rodrigues, 2001).

Figure B.2
TF34 Engine In-Work Times



RAND *MG418-B.2*

When this INW time distribution is compared to an exponential distribution with the same mean, the Kolmogorov-Smirnof test gives a p-value of less than 2.2e-16, which indicates that the distribution of engine INW repair times is indistinguishable from an exponential distribution. We therefore used an exponential distribution to model engine INW times.

Propulsion Requirements System

The PRS is used to both record and project aircraft engine removal rates as a function of engine operating hours. As part of its input, the PRS uses actuarial data for engine failure rates and engine repair time for peacetime and wartime scenarios. Two types of removal intervals are recorded—overhaul removal interval (OHRI) and base maintenance removal interval (BMRI)—which together produce the combined maintenance removal interval (CMRI). For the years 2002 and 2003 (a period that coincides with that of our CEMS data), these intervals are based on historical removal information. The CMRI is then used in conjunction with the future flying hour program to project engine removals by location. This study used the FY 2005 worldwide BMRI data to provide engine failure rates as a function of flying hours for those engine removals that would be inducted into the JEIM (ignoring engines inducted for depot overhaul). The only exception was the TF34 engine, for which CMRI data were used, because TF34s are not sent to the depot for overhaul.

In addition to estimates of engine removal rates, the PRS also includes standard peacetime and wartime engine repair times and transit times, which are used to calculate engine pipeline segments and engine authorizations (see Excel Management Systems, 2000).

Logistics Composite Model

Another estimate of engine maintenance times can be derived from the USAF LCOM, which is used to establish maintenance manpower requirements. LCOM is a Monte Carlo simulation that models the various failure modes of engines and the resources required to repair engines and return serviceable engines to flying units. In addition to establishing manpower requirements, it can produce estimates of engine repair time means and variances. If an effectively unlimited amount of maintenance and spares resources is allocated to the model, so that AWM and AWP times approach zero, a "pure" INW time can be estimated from LCOM simulation output. This time represents the average time needed to repair an engine given that parts, manpower, and facilities are available to do the work. We used USAF LCOM databases in this way to develop additional estimates, beyond those available from the CEMS data, for engine repair times.[6]

---

[6] The use of LCOM in determining maintenance manning and aircraft maintenance modeling is described in more detail in Dahlman, Kerchner, and Thaler, 2002.

Modeling Failure Processes for Electronic Warfare Pods

Because of the peculiar characteristics of EW systems, additional analysis and processing of historical maintenance data collected on these items were required to generate the removal rates needed to perform CONUS CIRF network designs for these pods. In this section, we describe this process.

ALQ-184 and ALQ-131

The ALQ-184 and ALQ-131 are self-protect ECM pods used on both A-10/OA-10 and F-16 aircraft. Currently, there are two versions of the ALQ-184 pod: the ALQ-184-Short and ALQ-184-Long. Because all ALQ-184-Short pods are being upgraded to ALQ-184-Long, this analysis considered all ALQ-184 pods to be the ALQ-184-Long version.

Determining a failure rate for ECM pods is somewhat difficult because pod use during peacetime training missions is limited, and ECM pods cannot be fully operated during most training missions because they interfere with civilian communications. Furthermore, pod BIT performs poorly in a non-threat environment, making it difficult to determine whether a pod is working correctly. In a combat environment, pod failures are readily evident via identified threats. Because the number of pod failures diagnosed during training missions is small, scheduled maintenance accounts for the majority of the ECM pod ILM workload during peacetime. ALQ-184-Long pods have a PMI of 90 calendar days; ALQ-131 pods have a PMI of 180 calendar days.

Peacetime ILM Induction Rates. Most ECM pod failures during peacetime training are delayed discrepancies, for which the failure is not diagnosed until the pod's next scheduled maintenance action. The ALQ-184 and ALQ-131 pods have different maintenance policies for a pod failure discovered during peacetime training. Whenever a failure is discovered for the ALQ-184, a full PMI test is not performed, and the pod's PMI clock is not reset to begin a new 90-day interval.[7] Whenever a failure is discovered for the ALQ-131, however, a full PMI test is performed, and the pod's PMI clock is reset to begin a new 180-day interval. WR-ALC provided data from the RAMPOD database indicating the percentage of maintenance events started because of a scheduled PMI versus jobs started because of a non-scheduled action (i.e., an observed failure).[8] Within this data set, the ALQ-184-Long had a total of 2,583 PMI jobs and 564 non-PMI discovered failures, indicating that unscheduled repairs accounted for 18 percent of ALQ-184-Long ILM inductions. For the ALQ-131, the data indicated a total of 1,455 PMI jobs and 736 non-PMI discovered failures, which means that unscheduled repairs accounted for 34 percent of ALQ-131 ILM inductions. Note that these data were collected over an interval that included significant deployed operations in support of OIF. Thus, the number of observed failures in this data set is likely greater than what would be expected during pure peacetime training. Despite their possibility of producing an overestimate, these data were used to compute a CONUS peacetime workload.

Because the observed failures constitute a purely additional workload for the ALQ-184 (i.e., unscheduled inductions do not impact a pod's PMI schedule), computing the ALQ-184 peacetime ILM workload is straightforward. The ratio of non-PMI discovered failures to PMI jobs is 0.22 for the ALQ-184-Long. Because ALQ-184 pods have on average 365/90 = 4.1 annual PMI inductions per pod, the unscheduled workload accounts for an average of 0.9 inductions per year per pod, yielding an annual peacetime training mean of 5 ILM inductions per ALQ-184.

For the ALQ-131, every non-PMI discovered failure resets the pod's PMI calendar and thus impacts that pod's scheduled workload. The data indicated that 34 percent of ALQ-131 ILM inductions occur because of unscheduled maintenance. This percentage can also be

---

[7] Personal communication, MSgt Kenneth Stevens, ACC/A4MA, via email, January 20, 2006.

[8] Data for January 2003 through June 2005 (ACC, AFRC, and ANG units only) provided by Malcolm Baker, WR-ALC/ITM, September 30, 2005.

interpreted as the probability that, within a single PMI, a pod has an observed failure before its PMI expiration.

The exponential probability distribution is commonly used to model the reliability of electronic components. The exponential distribution applies to components that have a constant failure rate, which means the probability of a component failing at any point in time is independent of how long the component has been functioning. This is equivalent to assuming that components do not deteriorate or improve (over the main portion of their useful life) and is referred to as the "memoryless" property.

Define the failure rate λ as the likelihood of a component failing in one unit of time. The exponential distribution has a known cumulative density function $F(t) = 1 - e^{-\lambda t}$, where $F(t)$ denotes the probability that a component functioning at time 0 will have failed by time t. If the percentage of pods that have failed at the end of the PMI is known, the pod failure rate λ can be computed via the following formula:

$$\lambda = \frac{-\ln\left[1 - F(t)\right]}{t}. \tag{B.1}$$

Assume that, during peacetime, the time until an ALQ-131 failure is observed follows an exponential probability distribution until 180 days, at which point a PMI is performed on any pod that has not had any observed failures. In this case, the rate at which pod failures are observed in peacetime (during the first 180 days following an ILM induction) can be computed using Equation B.1. Thus, $F(180) = 0.34$ implies that there are $\lambda = 0.00227$ observed ALQ-131 failures per calendar day per pod during peacetime training. Therefore, during peacetime training, the overall PDF of the ALQ-131 ILM induction time is

$$f(t) = \begin{cases} 0.00227e^{-0.00227t} & 0 \le t < 180 \\ 0.66 & t = 180 \\ 0 & \text{otherwise.} \end{cases} \tag{B.2}$$

The mean time between peacetime ALQ-131 ILM inductions can now be computed as follows:

$$\int_0^{180} 0.00227te^{-0.00227t}\,dt + 180\left(0.66\right) = 147. \tag{B.3}$$

Thus, the peacetime workload is $365/147 = 2.5$ mean annual ILM inductions per ALQ-131.

Deployment ILM Induction Rates. Recall that in a deployment setting, ECM pod failures are observed immediately because of the high-threat environment. Furthermore, while ECM pods are used irregularly during peacetime training missions, a functioning ECM pod is required on every deployed sortie. Delayed discrepancies make it difficult to determine the pod failure process from historical deployment data, because units deploy with pods whose undiagnosed failures are observed immediately upon use in the deployment setting. Such an effect would lead to an overestimate of the failure process in the early stages of a deployment. However, our study examined a scenario in which deployed operations were to be sustained indefinitely, so an estimate of the actual ECM pod failure process is required.

ECM pod PMI data were obtained from the RAMPOD database, which contained five years of scheduled pod PMI jobs, comprising a total of 4,227 ALQ-184-Long PMI inductions and 3,048 ALQ-131 PMI inductions.[9] Of these scheduled jobs, 1,958 of the ALQ-184-Long jobs were subsequently determined to have failures, and 1,441 of the ALQ-131 PMI jobs had failures. These data suggest that 46 percent of ALQ-184-Long pods had failed at their 90-day PMI, while 47 percent of ALQ-131 pods had failed at their 180-day PMI. Note that this data set does not include unscheduled pod removals, which we excluded because of uncertainties about the confirmation of observed failures (i.e., instances when the ILM cannot duplicate the observed failure on the test stand) and the aforementioned difficulties associated with delayed discrepancies in the early stages of deployments (assuming that almost all PMI jobs occur during peacetime training because of the

---

[9] Data for January 1999 through January 2004 provided by Malcolm Baker, WR-ALC/ITM, May 4, 2004.

heavier flying schedule and immediate pod failure detections associated with deployment operations). Note that the exclusion of these unscheduled removals may potentially produce an underestimation of the pod failure rate.

Assume that the time until an ECM pod failure (whether observed immediately or not) follows the exponential probability distribution. For the ALQ-184-Long, $F(90) = 0.46$ implies that $\lambda_{ALQ-184} = 0.0069$ failures per calendar day per pod. Similarly, for the ALQ-131, $F(180) = 0.47$ implies that $\lambda_{ALQ-131} = 0.0036$ failures per calendar day per pod.

Assume that pod failures only occur during pod operating hours. These rates then need to be converted into failures per pod operating hour to account for differences between the peacetime training and deployment environments. If one uses a weighted average across pre-BRAC CONUS ALQ-184 and ALQ-131 operating units, the peacetime flying schedules from Table B.3 imply 23.76 flying hours per month per ALQ-184–equipped PAA, and 24.58 flying hours per month per ALQ-131–equipped PAA. Note that CONUS units have additional pods assigned, beyond their PAA levels. Pre-BRAC, these CONUS units had 1.105 ALQ-184 per PAA and 1.118 ALQ-131 per PAA. Multiplying the rate λ by the pods per PAA divided by the peacetime flying schedule (converted into calendar days) yields failure rates of 0.0098 ALQ-184 failures per flying hour and 0.0049 ALQ-131 failures per flying hour. Recall that ECM pods are not used on all peacetime training sorties. Assuming that ECM pods are operated for one-half of the units' CONUS peacetime flying hours, the following ECM pod failure rates are obtained: 0.0196 failures per ALQ-184 operating hour and 0.0098 failures per ALQ-131 operating hour.

This is equivalent to stating that the ALQ-184 has an MTBF of 51 hours, and the ALQ-131 has an MTBF of 102 hours. Data obtained from the RAMPOD database[10] indicated an MTBF of 132 hours for the ALQ-184, with an associated MTBF of 122 hours for the ALQ-131. These RAMPOD data estimates are computed as the total

---

[10] Personal communication, Robbie Ricks, WR-ALC/ITM, via email, 2004.

pod operating hours divided by the number of failed pods and are thus greatly affected by delayed discrepancies. The USAFE CIRF test report (HQ USAF, 2002) presents a fleetwide average MTBF of 82 hours for the ALQ-131, although the effects of delayed discrepancies on the early stages of a deployment would be expected to produce an overestimate of pod failure rate. The 102-hour MTBF used by our study for the ALQ-131 lies in the interval between these likely under- and over-estimates.

The next step is to compare these computed pod failure rates, which are immediately observed in a deployed environment, with the peacetime ILM pod induction rates. Assuming that ECM pods are used on every deployed sortie, daily pod failure rates can be computed for notional squadrons. Assume that deployed squadrons of 24 PAA support the deployment flying schedules presented in Table B.2. If ALQ-184–equipped aircraft are deployed, such an A-10 squadron will generate 1.18 ALQ-184 pod failures per day, and such an F-16 squadron will generate 1.65 ALQ-184 pod failures per day. If the deployment utilizes ALQ-131 pods, such an A-10 squadron will generate 0.59 ALQ-131 pod failures per day, and such an F-16 squadron will generate 0.82 ALQ-131 pod failures per day.

Assume that during its peacetime training mission, a squadron of 24 PAA of either MDS has 28 assigned pods. The peacetime ILM pod induction rate for such a squadron would be 0.384 ALQ-184 and 0.192 ALQ-131 inductions per day. Thus, the deployed A-10 squadron would observe a pod failure rate 3.1 times greater than its peacetime ILM pod induction rate for either pod. The deployed F-16 squadron would observe 4.3 times as many pod failures versus its peacetime ILM pod induction rate for either pod. Previous research (Feinberg et al., 2002) indicated that during Joint Task Force Noble Anvil, the actual removal rate for deployed ALQ-131 pods was 3.0 times greater than the predicted peacetime removal rate. The USAFE CIRF test report noted that one ANG unit deployed in support of OEF observed ALQ-131 failure rates 4.8 times greater than the historical average. While the contrasts between deployed failure rates and peacetime workloads computed in our study do not correspond exactly to these results, they do demonstrate an increase in deployment ILM pod workload that is consistent with these recent experiences.

F-15 Avionics

There is no single source for obtaining the failure rate and repair time data needed for the F-15 avionics LRUs. Avionics LRUs may be classified into three sets: EW LRUs, which are tested on the TISS; radar LRUs, which are tested on the ANT A/B or the Enhanced Aircraft Radar Test Station (EARTS); and other LRUs, which are tested on either the AIS or the ESTS.

To size ILM facilities, we examined the relationship between utilization rate and expected LRUs AWM. Because the distribution of INW times for the various LRUs fits an exponential distribution, we used standard equations for Markovian systems to determine the expected number of ESTS LRUs that would be either INW at a station or awaiting a station for service (does not include any LRUs that are INT). As Figure B.3 indicates, the AWM queue is small as long as overall utilization at that maintenance location is below 85 percent, so we set maximum utilization at 85 percent.

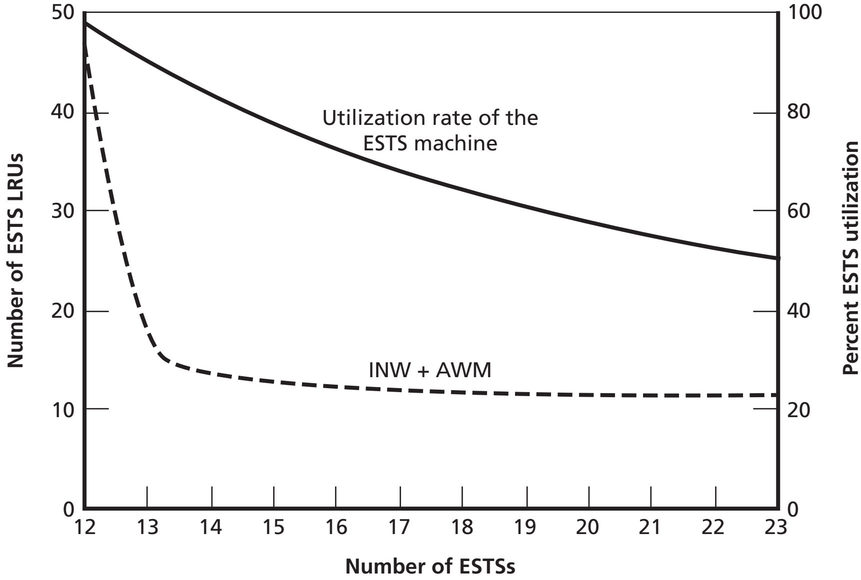
Inventory information was obtained from the CLS of the Readiness Based Leveling (RBL) database, which includes spares information by base (U.S. Air Force, 2004). The inventories shown in Table B.4 are those identified as assigned to CONUS F-15 bases only.[11]

LRU failures are modeled as a function of flying hours. The CLS RBL contains D200 data that estimate the failure rate in terms of flying hours. We multiplied these failure rates by the flying hour program and the PAA for each location to forecast the overall daily failure rate by location. Planning factors such as removal rates, NRTS rates, cannot

---

[11] See Peltz et al., 2000, for further detail on these LRUs.

Figure B.3
Relationship Between AWM Queue and Utilization



RAND *MG418-B.3*

Table B.4
Avionics CONUS Inventory

LRU	Base Stock	LRU	Base Stock
ESTS			
022	29	HUD	48
025	4	HUD SDP	26
038	15	IB	14
039	29	ICCP	93
042	34	IFF C/P	14
044	1	ILS R/T	14
081	31	IRE	44

Table B.4—Continued

LRU	Base Stock	LRU	Base Stock
082	7	MPCD	34
ADC	48	MPD	17
ADF ECA	3	MPDP	8
AIU 1	0	NCI	47
AIU 2	3	PACS CP	29
ASA	7	Pitch Computer	40
BCP	21	PSDP	46
CLLU	30	RFO	15
DSA	28	Roll/Yaw CPTR	26
EAIC	47	RSCP (20)	14
ECA	22	RSCP (21)	3
ECSP	20	TACAN Mount	8
EMD	14	UFCP	0
FCC	7	VHSIC CC	28
FDA	27	WFOV HUD	16
TISS			
Band 1 amplifier	29	Band 3 control oscillator	11
Band 1 control oscillator	27	Receiver transmitter	37
Band 1.5 amplifier	2	Radar warning receiver power amplifier	43
Band 1.5 control oscillator	6	High band receiver	93
Band 2 amplifier	6	Countermeasure receiver	47
Band 2 control oscillator	8	Countermeasure display	30
Band 3 amplifier	44		

.

Table B.4—Continued

LRU	Base Stock	LRU	Base Stock
ANT			
Radar antenna	58	Radar transmitter	35
Radar power supply	38	Radar transmitter	20

NOTE: See Peltz et al., 2000, for further details

duplicate (CND), and BSLs for each of the LRUs are also found in the CLS RBL Production System.

To model INW time, the INW times of the various LRUs tested on each of the three stations were weighted by the demand rate to find the weighted average INW time for ESTS, TISS, and ANT A/B stations. Because no single LRU dominated maintenance demand, the workload was based on an aggregated demand for maintenance.

Of particular interest are systems that will be maintained on the ESTS, a second-generation test set that takes the place of five individual test stations in the original F-15 AIS. Because F-15 avionics ILM locations are currently being transitioned to the ESTS, the reported INW times are actually a mix of ESTS and AIS times. The ESTS System Program Office measured INW time on ESTS to provide INW times for LRUs maintained on the ESTS.

Avionics systems maintenance also experiences the phenomenon of BCS LRUs. In this case, LRUs indicated as failed by on-wing BIT checks are found, upon examination at the test station, to be in serviceable condition and not in need of further service. Historical data indicate that INW time observed for an LRU that is determined to be BCS is less than the standard INW time for that LRU. For each LRU, the fraction of LRUs determined to be BCS was obtained by analyzing Eagle Eye records from Seymour-Johnson and Langley AFBs. Eagle Eye is used by individual avionics ILM shops to track LRU inductions by LRU type, serial number, discrepancy, and a classification (CND/BCS, Repairable, or NRTS).

LANTIRN

Inventory levels were obtained from Marty Hutchinson of the Avionics Management Directorate Precision Attack System Program Office (WR-ALC/LY-PASPO).

TGT pod shipping costs were based on the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004), with pod transit times obtained from the DoD Standard Transit Time Guide (U.S. DoD, 2006). NAV pod LRUs used express shipping under the SDDC Domestic Small Package Express Blanket Purchase Agreements under 2nd day air (with a third day allotted for processing).

APPENDIX C

Detailed Results of JEIM Analyses

This appendix provides a detailed report of the CONUS CIRF analyses we performed in support of the TF34, F110, and F100 jet engines. A shortened version of these results is presented in Chapter Three; it discusses both the post-BRAC CONUS JEIM network and an alternative CIRF network, including each network's cost and performance for each engine type, and describes in abbreviated form the detailed results for the F110 engine. The purpose of this appendix is to document the data and analytic processes used to generate our findings for these engines.

The BRAC Report recommendations establish several CONUS CIRF relationships, all of which are assumed to be fixed in our analysis even though additional supported units may potentially be added to BRAC-designated CIRFs.

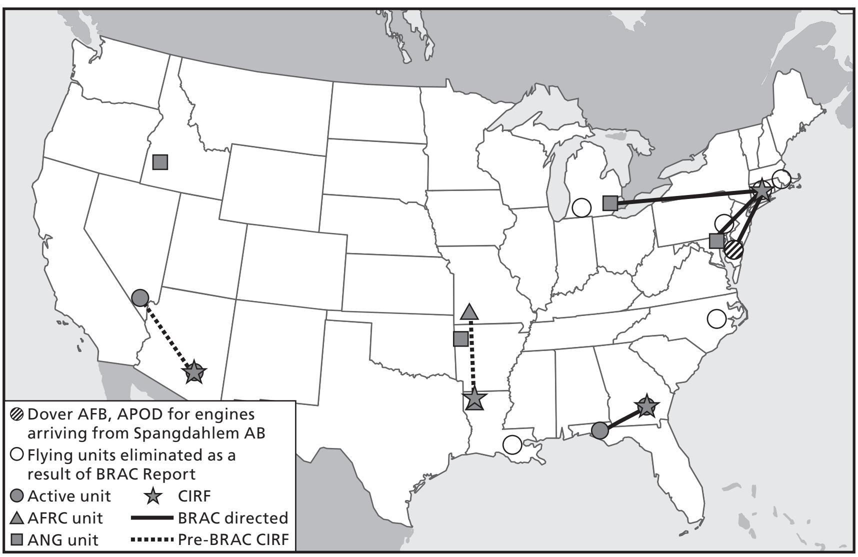
TF34 Engine

The TF34 engine is used in the A-10/OA-10 aircraft, with two engines per aircraft. Post-BRAC, ten CONUS flying units will operate this engine. The BRAC Report designates two TF34 CIRFs. Bradley ANG loses its A-10 flying unit but becomes a CIRF, supporting Selfridge ANG, Martin State ANG, and Spangdahlem AB. Moody AFB will operate a CIRF supporting Eglin AFB. Some TF34 CIRF structure existed prior to the BRAC deliberations. Barksdale AFRC provided a CIRF for New Orleans AFRC (retiring) and Whiteman AFRC. Similarly, Davis-Monthan AFB provided JEIM support for Nellis AFB.

Shaw AFB, which does not have an A-10 flying unit, operated a CIRF for Pope AFB (retiring), Eglin AFB, and Spangdahlem AB. The BRAC Report designates the closure of the TF34 CIRF at Shaw AFB; however it does not specify any actions regarding the CIRF arrangements at Davis-Monthan AFB or Barksdale AFRC. Thus, the Davis-Monthan AFB and Barksdale AFRC CIRF arrangements are not assumed to be fixed based on the BRAC Report and may potentially be realigned in this analysis.

Figure C.1 presents a map of the units using the TF34 engine. Note that the point representing Dover AFB (Delaware) indicates the aerial port of debarkation (APOD) for those engines arriving from Spangdahlem. Currently, these engines are flown via AMC into Dover and shipped via air-ride truck from Dover to the CONUS CIRF. For this study, we assumed that these engines emanate from Dover and ignored the transit cost and engine pipeline between Germany and Delaware (since this Spangdahlem-Dover cost and pipeline would be constant

Figure C.1
TF34: Post-BRAC Network



RAND *MG418-C.1*

for any CONUS CIRF receiving engines from Dover). The uncolored circles in the figure represent flying units eliminated as a result of the BRAC Report.

Table C.1 presents further detail on the network of TF34 bases. Locations considered for potential TF34 CIRF sites include Shaw AFB, Bradley ANG, and all post-BRAC operating locations except Spangdahlem AB/Dover AFB and Eglin AFB. No other potential CIRF locations were considered in this analysis.

TF34: Deployment Scenario Data and Inputs

The total CONUS A-10/OA-10 PAA is 270. The deployment scenario presented in Appendix B accounts for a deployment of 38 A-10 PAA. It was assumed that the 38 deployed aircraft would have their TF34 JEIM performed at an OCONUS CIRF staffed entirely by personnel

Table C.1
Post-BRAC TF34 Operating Locations

Base Name	MAJCOM	PAA
Davis-Monthan AFB	ACC	66
Nellis AFB	ACC	10
Moody AFB	ACC	48
Spangdahlem AB (Dover AFB)	USAFE	18
Eglin AFB	AFMC	2
Boise ANG (Idaho)	ANG	18
Fort Smith ANG (Arkansas)	ANG	18
Martin State ANG (Maryland)	ANG	18
Selfridge ANG (Michigan)	ANG	24
Barksdale AFRC	AFRC	24
Whiteman AFRC	AFRC	24

SOURCES: 2005 Defense Base Closure and Realignment Commission, 2005; data from AF/XPPE, 2005.

deploying from the CONUS CIRFs. Under this scenario, the 38 A-10 deploy to two different FOLs, each with 19 aircraft.

Pre-BRAC, the total CONUS A-10/OA-10 PAA was 265 (including Spangdahlem). The pre-BRAC CONUS BSL spare engine allocation was 117 spare engines (including Spangdahlem). The pre-BRAC total CONUS (plus Spangdahlem) WRE allocation was 42 engines. The BRAC Report realigns the A-10/OA-10 aircraft at Eielson AFB to CONUS units. Thus, Eielson's 14 BSL and eight WRE were added to the spare engines available in this analysis, and no pre-BRAC spare engines were retired, leaving a total of 131 BSL and 50 WRE.[1] Within this deployment scenario analysis, the CONUS WRE goal was reduced by 20 percent to reflect the 20 percent of combat-coded PAA already deployed.

The transit times between bases were obtained using the DoD Standard Transit Time—Truckload (U.S. DoD, 2006). Two additional days were added to each transit leg to allow for transit preparation time. The transport costs were obtained from the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004) assuming an air-ride truck with expedited service and dual drivers for each shipment. Table C.2 contains the transport costs assumed for CONUS engine shipments. We assumed that no engine pipeline or transit cost was encountered for those engines receiving JEIM at their home-station bases. We also assumed a 15-day, one-way transit time from any

Table C.2
CONUS Engine Transport Costs

Distance Traveled	$ per Mile
1 to 500	2.40
501 to 1,000	2.30
1,001 to 1,500	2.19
>1,500	2.00

[1] BSL engine inventories and WRE goals are from C. R. McIntosh, FY04 F100F110TF34 BSL Goals CA CONUS.xls, OC-ALC/LR, August 30, 2004a.

FOL to the OCONUS CIRF.[2] Note that OCONUS transit cost was not considered in this study.[3]

TF34 failures are generally expressed in terms of an MTBF that is a function of engine operating hours. The Air Force PRS MTBF estimate is 851 hours per TF34 removal (Strong, FY2005). To compute a base's engine induction rate into the JEIM, one multiplies its number of PAA by its flying schedule (see Appendix B) by two (since there are two TF34 engines per aircraft) and divides by 851. For this scenario, this implies a total mean daily failure rate, summed across both CONUS and deployed engines, of 0.78 engine failures per day.

A mean engine repair time of 200 hours per JEIM induction was computed, with an average of 18 of those hours spent at the test cell and no retained tasks identified (see discussion of data modeling in Appendix B). CONUS JEIM shops were assumed to operate 16 hours per day, five days per week, requiring two eight-hour shifts per line and a 40-hour workweek per man. The OCONUS CIRF was assumed to operate 24 hours per day, seven days per week, with two daily shifts of 12 hours each and a 60-hour workweek per man. It was assumed that OCONUS FOLs sent all engine failures to the OCONUS CIRF. Significant economies of scale in JEIM manpower were identified from the LCOM simulation analysis described in Appendix A. Standard Air Force man-hour availability factors were used to account for the effects of weekends, sick leave, etc., on manpower availability (HQ ACC/XPM, 2003). For a normal 40-hour workweek, this requirement is 1.038 manpower positions to fill one shift position. For a 60-hour workweek, this requirement is 1.461 manpower positions to fill one shift position. An additional 10 percent manpower requirement was

---

[2] We deliberately used an exceedingly conservative OCONUS transit time to demonstrate the supportability of the TF34 within a CIRF framework. During the USAFE CIRF test, average one-way transit times of 4.3 to 6.2 days were observed for the F100 and F110 engines (TF34 engines were not tested; see HQ USAF, 2002).

[3] OCONUS transport costs were not included because they are not affected by the CONUS CIRF network design. However, estimates of potential OCONUS-CONUS transport costs are presented later in this appendix (see TF34 Deployment Scenario: All Repair in CONUS, pp. 157–160).

added to each case to account for management and support positions needed beyond direct maintenance manpower.

We made no differentiation between "types" of full-time manpower—e.g., active duty versus ANG. A dissimilarity does exist, however, between the active duty and reserve components with regard to their use of JEIM personnel. Within active duty JEIM shops, JEIM personnel only perform ILM. This is not the case with the reserve components, who not adhere to such a distinction with jet engine maintenance personnel. Maintenance personnel from reserve component JEIM shops are regularly dispatched to the flightline to assist with organizational-level maintenance tasks. Thus, any reserve component unit that loses its JEIM cannot be divested of its total JEIM manpower. A "dispatch team" must be retained to perform these additional non-JEIM duties at the unit. Some precedent for this exists within the current AFRC TF34 CIRF arrangement. The AFRC units at New Orleans AFRC and Whiteman AFRC have their JEIM performed at a CIRF at Barksdale AFRC. New Orleans AFRC and Whiteman AFRC each retain three full-time JEIM personnel,[4] ostensibly to perform these additional tasks. Therefore, within this analysis, any reserve component squadron that loses its JEIM capability retains a dispatch team of three or four personnel per squadron (depending on squadron size) to perform these additional duties.

The pre-BRAC manning at these units, obtained from Unit Manpower Documents (UMDs),[5] was determined to be 314 full-time positions, with 260 drill positions in the ANG and AFRC. Note that 124 of these drill personnel are also counted within the 314 full-time positions, so 450 total TF34 JEIM manpower personnel were available in CONUS to support contingency operations. Annual manning costs were assumed to be \$60,000 per full-time position and \$15,000 per drill position,[6] giving a pre-BRAC annual manning cost of \$22.7 million.

---

[4] Massey, 2004.

[5] Massey, 2004.

[6] SAF/FMBOP, undated.

The JEIM operating cost was defined as the associated personnel cost using a factor of $60,000 per man-year. The only CIRF setup cost considered was the cost required to obtain additional test cell equipment. It was assumed that a CIRF would not operate under the command of the local operating unit, which would retain its own test cell (or hush house) for testing installed engines. Thus, it was assumed that any base performing only its own home-station repair would continue to use its existing test cell capabilities and would not incur this test cell setup cost. It was further assumed that no test cell setup cost would be incurred for any currently existing CIRF relationship (i.e., Nellis AFB at Davis-Monthan AFB, and Whiteman AFRC at Barksdale AFRC). However, the assignment of any additional supported units to an existing CIRF would cause the test cell setup cost to be incurred. OCONUS test cell costs were not considered in this analysis.

It was assumed that the T-9 test cells required at a CIRF could be obtained from the associated bases that were losing their JEIM. However, a building would need to be constructed to house the test cell, along with an augmentor/deflector repack kit and fire suppression, at a total cost of $3.9 million. These test cells require a major maintenance action every five years, costing between $500,000 and $1 million. Thus, the test cell setup and maintenance costs were discounted over a five-year interval at a real discount rate of 2.1 percent (Office of Management and Budget, 2004), resulting in an annualized cost of $1 million per additional CIRF test cell. No constraint was assumed on the number of rail teams available, since engine rails are rather inexpensive compared with their associated manning costs.

Recall that the current CONUS (plus Spangdahlem and Eielson) BSL inventory is 131 spare engines, with a total WRE allocation of 50 engines. Data obtained from the OC-ALC indicate an average AWP of 6.0 percent of BSL spare engines (worldwide).[7] Due to the higher tempo of the deployed flying schedule, the AWP fraction was increased proportionally to the deployment scenario's increased failure rate when compared against the purely peacetime flying schedule.

---

[7] Data from January 2003 through December 2004, TF34 WW ENMCS% and TF34MetricsDec04.ppt, provided by C. R. McIntosh, OC-ALC/LR, January 12, 2005.

Multiplying this increased AWP value by the CONUS-wide spare pool of 131 engines gives a mean expectation of 9.6 AWP engines. It was also assumed that the JEIM structure would have no effect on repair rates. Given the assumed repair rates and accounting for the differences in CONUS and OCONUS work schedules and flying schedules, a total mean of 11.5 engines INW is expected across the CONUS and OCONUS CIRFs, independent of the CONUS JEIM network. Note that the OCONUS INT pipeline, containing a mean of 6.8 engines, is also independent of the CONUS JEIM structure. These considerations yield a maximum possible mean serviceable spare value of 103 engines (assuming zero engines AWM and zero engines in the CONUS INT pipeline).

TF34: Deployment Scenario

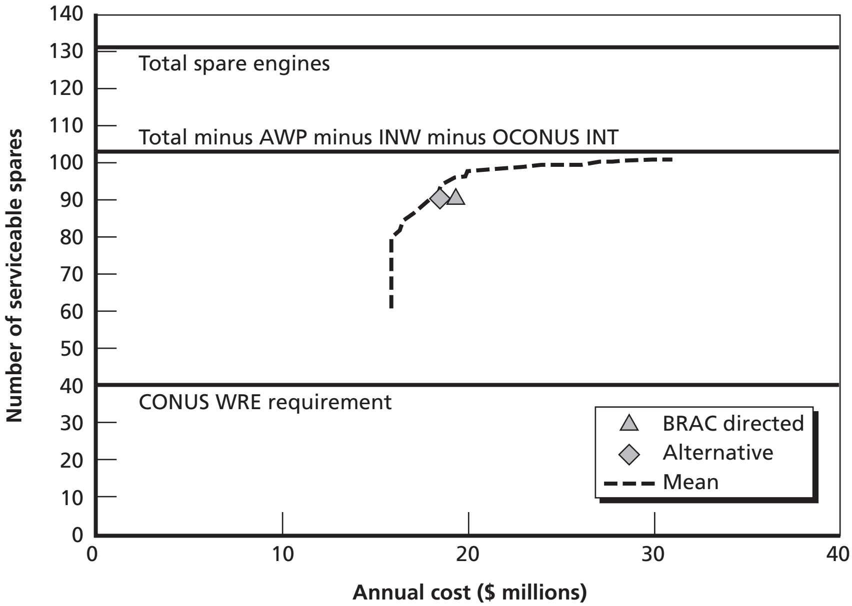
Figure C.2 presents the results of the deployment scenario analysis for the TF34 JEIM structure, demonstrating the tradeoff between annual cost (transport cost, plus operating cost, plus annualized test cell setup cost) and number of serviceable spares available. The optimization model presented in Appendix A was used to identify the points defining this curve, which demonstrates the best system performance available for any level of expenditures. Note that this efficient frontier curve actually represents a very large number of potential solutions: For any point of interest along this curve (e.g., 100 serviceable spares at a cost of $24 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the total combat-coded CONUS PAA, the serviceable spare level can be kept far above the residual WRE requirement.

Data obtained from OC-ALC indicate that over the two-year period of 2004–2005, net serviceable engines equaled, on average, 57.6 percent of allocated BSL engine inventories (worldwide).[8] Applying this rate to the CONUS-wide BSL allocation of 131 engines implies that a mean of 75 net serviceable engines could be expected from the current

---

[8] Data from January 2003 through December 2004 (Net Serviceable/Allocated BSL) and TF34MetricsDec04.ppt provided by C. R. McIntosh, OC-ALC/LR, January 12, 2005.

Figure C.2
TF34 CIRF Network Options: Deployment Scenario



RAND *MG418-C.2*

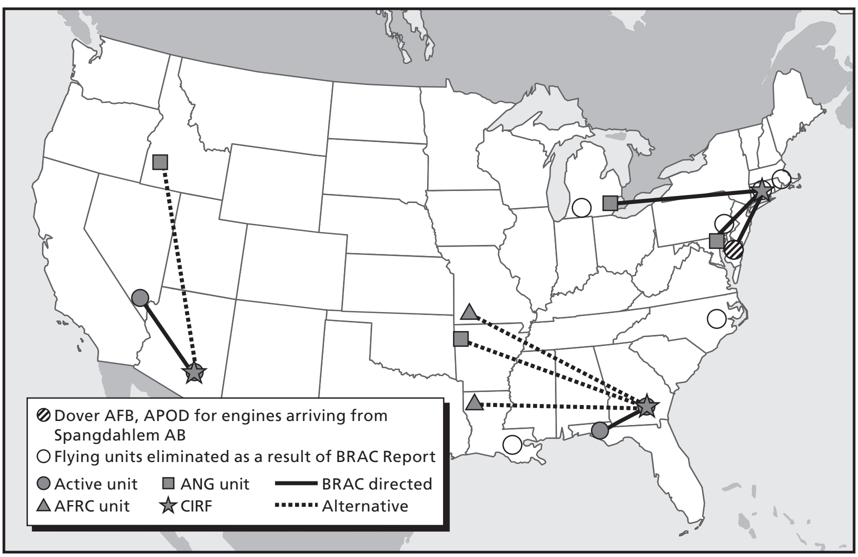
CONUS JEIM network. However, these data do not reflect the post-BRAC force structure. Moreover, the worldwide engine availability data do not reflect the same deployment flying schedule (this two-year period includes support of OIF), making a direct comparison with these results somewhat difficult. To provide a fairer basis for comparison, the post-BRAC TF34 network presented in Figure C.1 was evaluated using the decision model. It achieved 91 serviceable spare engines at a total cost of $19.3 million.

Rather than recommending any single network design as optimal, our analytic process identifies a set of alternative network designs lying along an efficient trade-space in which each identified network achieves the best possible weapon system support for its level of cost. For example, it is possible to identify a point on the efficient frontier curve of Figure C.2 that achieves comparable performance to the post-BRAC network (91 serviceable spare engines) at a slightly reduced cost

($18.5 million). The network configuration associated with this alternative solution is presented in Figure C.3. Note that both solutions maintain a serviceable spares level greatly exceeding the residual WRE requirement of 42 engines.

The alternative CIRF network has a total full-time manpower requirement of 251, with a total manning of 180 at the CONUS CIRFs, 50 manpower positions at the OCONUS CIRF, and a total of 21 dispatch team positions at the six CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 285, with a total manning of 224 at the CONUS CIRFs/JEIM shops, 50 manpower positions at the OCONUS CIRF, and a total of 11 dispatch team positions at the three CIRFed reserve component units. Notice that the alternative solution requires 34 fewer full-time maintenance positions but requires greater expenditures for additional transportation and for test cell setup at the expanded Davis-Monthan AFB CIRF.

Figure C.3
TF34: Alternative CIRF Network



RAND *MG418-C.3*

It should be noted that CONUS CIRFed units have a workload associated with shipping and receiving engines to/from the CIRF. While this work could reasonably be performed by the dispatch teams remaining at CIRFed reserve component units, it would constitute an additive workload for the remaining personnel at CIRFed active component units without retained task teams. For the alternative CIRF network presented in Figure C.3 and the deployment scenario under consideration, the expected annual TF34 shipping/receiving workloads range from one engine at Eglin AFB to 16 engines at Spangdahlem AB. Assuming two man-days for shipping preparation at the base and one man-day for receipt of engines from the CIRF, this annual workload equates to three man-days at Eglin AFB (approximately 0.01 man-year) and 48 man-days at Spangdahlem AB (approximately 0.18 man-year).

TF34 Deployment Scenario: All Repair in CONUS

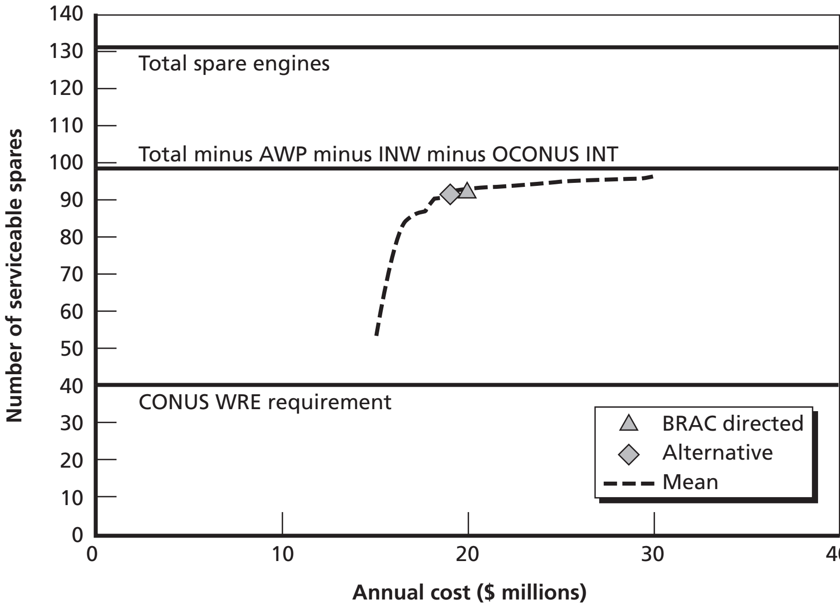
The manpower requirement just discussed (see above) is potentially misleading. Recall that this scenario places 20 percent of the CONUS combat-coded fleet in a perpetually sustained deployment, necessitating a perpetually operating OCONUS CIRF. While an OCONUS CIRF's physical infrastructure can be thought of as permanent, individual maintenance personnel cannot be deployed OCONUS indefinitely; a rotational manpower pool is needed. The relative size of the rotational pool depends on the deployment burden deemed acceptable for maintenance manpower. If the alternative network's total CONUS manning of 201 personnel (including the dispatch team members) is used to support its OCONUS manpower requirement of 50 positions, all full-time JEIM personnel will be required to spend one-fifth of their time deployed OCONUS. This is consistent with the general AEF construct, wherein full-time USAF personnel are eligible to spend one-fifth of their time deployed, implying that five full-time manpower positions are required systemwide to support one position perpetually deployed.

Note the assumption that dispatch team positions are interchangeable with CIRF positions. If this assumption is not valid, the deployment burden on JEIM personnel will be greater. If dispatch team positions are not interchangeable with CIRF positions, the total manpower requirement would be 271 full-time positions for the alternative network, with 250 CIRF positions required to support a perpetual deployment of 50 positions, and 21 dispatch team positions required. At any point in time, 221 of these full-time CIRF and dispatch team positions would be within CONUS, which is greater than the 201 manpower positions required for the residual CONUS fleet's workload.

An alternative policy to the use of OCONUS CIRFs is to retrograde all OCONUS engines requiring JEIM from the FOLs to the CONUS CIRFs. Such a policy imposes a significant burden on the transportation system but eliminates the rotational burden on manpower. Note that the use of OCONUS CIRFs is also heavily dependent on transportation, both for the movement of engines between FOLs and the OCONUS CIRF and for the rotation of JEIM personnel between the CONUS and OCONUS CIRFs. This alternative maintenance policy was tested against the same deployment of 38 A-10 PAA. A 21-day, one-way transit time from any FOL to any CONUS CIRF was assumed. Also, it was assumed that the CONUS CIRF would maintain its work schedule of 16 hours per day, five days per week. Figure C.4 presents the efficient frontier curve resulting from this alternative policy analysis. The CONUS WRE requirement was again reduced by 20 percent to reflect the deployment of 20 percent of PAA. The deployment scenario's flying schedule again accounts for a mean of 9.6 AWP engines. Accounting for the CONUS work schedule, a total mean of 13.6 engines is expected INW across the CONUS CIRFs. As before, the OCONUS INT pipeline is independent of the CONUS ILM structure; because of the increased transit time, this pipeline contains a mean of 9.5 engines. These considerations yield a maximum possible mean serviceable spare value of 98 engines (assuming zero engines AWM and zero engines in the transit pipeline for CONUS units).

Note that the mean serviceable spare level for this policy remains far above the residual CONUS WRE requirement. A comparison between the post-BRAC network of Figure C.1 and the alternative network of Figure C.3 reveals that the two networks achieve similar

Figure C.4
TF34 CIRF Network Options: All Repair in CONUS



RAND *MG418-C.4*

performance (92 serviceable spare engines in each case) at comparable cost ($19.1 million for the alternative network versus $19.9 million for the post-BRAC network). The alternative CIRF network has a total full-time manpower requirement of 261, with a total manning of 240 at the CONUS CIRFs, and a total of 21 dispatch team positions at the six CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 295, with a total manning of 284 at the CONUS CIRFs/JEIM shops, and a total of 11 dispatch team positions at the three CIRFed reserve component units. Recall that OCONUS transit cost was not modeled in this study; however, transit between FOLs and CONUS CIRFs is unlikely to be very costly. The cost to transport a TF34 at the AMC channel rate between Dover

AFB and Al Udeid (for example) is $3,419 each way.[9] This deployment scenario has an annual requirement of 82 engine shipments each way between the FOLs and CONUS CIRFs, producing an associated annual transit cost of $561,000.

TF34: Other Considerations

The comparable performance of the policy of all repair in CONUS and the OCONUS CIRF policy (92 versus 91 serviceable spares, respectively) masks some important distinctions in system performance. Under the OCONUS CIRF policy, the OCONUS CIRF operates a greater number of hours per week (168 versus 80 hours for the all repair in CONUS policy), with individual JEIM personnel working more hours per week (60 hours versus 40). An expected overall savings of 2.1 engines at the JEIMs would be realized because of the OCONUS increased operating schedule. The all repair in CONUS policy also requires an additional 2.7 engines for the OCONUS-CONUS transport pipeline. This policy is able to offset these engines because of decreases in AWM attributable to its larger facilities. However, the most significant distinction between the two policies is the difference in deployment burden: the OCONUS CIRF policy requires all full-time JEIM manpower to spend one-fifth time deployed, whereas the all repair in CONUS policy has no deployment requirement for JEIM manpower.

If JEIM manpower is designed to support sustained deployment operations assuming 24 hours per day, seven days per week shop operations, and a 60-hour workweek (as in the OCONUS CIRF policy), little additional capacity is available to support more-stressing, surged operations. Note that the all repair in CONUS policy is able to perpetually sustain deployment operations using a standard workweek of two shifts by 40 hours. This CIRF policy could provide additional support during surged operations through the utilization of its assigned manning in a 60-hour workweek environment, potentially extending

---

[9] TF34-GE-100 dry weight is 1,440 lb (General Electric, 2007); AMC channel rate between Dover AFB and Al Udeid is $2.374 per lb each way (U.S. Government, 2005).

the capability of JEIM to support surged operations. Note that such considerations may also impact WRE requirement computations.

The MRC scenario presented in Appendix B was used to determine the part-time manning requirement necessary in the reserve component. For the TF34, this scenario involves 96 PAA deploying to each of two theaters. Because this MRC scenario is not assumed to be the perpetual condition for USAF forces, the effects of deployment burden receive less attention, and the minimization of strategic airlift receives priority, leading to an assumed policy wherein deployed aircraft receive all JEIM from their unique in-theater OCONUS CIRF. The CONUS residual aircraft receive JEIM from the CIRFs at Davis-Monthan AFB (supporting itself and Nellis AFB) and Moody AFB (supporting Barksdale AFRC and Eglin AFB). The CONUS manning requirement is computed to be 72 positions, and each OCONUS CIRF requires 118 manpower positions, giving a total manning requirement of 308. The difference between these 308 positions and the 20 percent deployment manpower defines the part-time manning requirement.

The efficient frontier curves presented in Figures C.2 and C.4 represent a very large number of potential solutions. Each point lying on these curves is associated with a specific CIRF network design. Table C.3 summarizes the maintenance, transportation, and equipment (annualized test cell setup) costs, as well as the system performance and manpower requirements associated with the 20 percent deployment scenario for the post-BRAC and alternative CIRF networks. Note that the part-time manning requirement necessary to support a large-scale MRC deployment is also included.

It should be noted that the total CONUS TF34 WRE requirement is only 50 engines; the alternative CIRF solution (along with other solutions lying on the curves) greatly exceeds the required performance for both policies considered, in support of perpetually sustained deployment operations. These results indicate that a small number of TF34 CIRFs can provide a cost-effective solution while attaining acceptable performance.

Table C.3
Cost and Performance: TF34 CIRF Networks

	With OCONUS CIRFs		All Repair in CONUS	
	BRAC Directed	**Alternative**	**BRAC Directed**	**Alternative**
Maintenance locations (CONUS/OCONUS)	6/1	3/1	6/0	3/0
Serviceable spares	91	91	92	92
Payroll ($M)	17.4	15.9	17.9	16.4
Transportation ($M)	0.1	0.3	0.1	0.3
Test cell ($M)	2.1	3.1	2.1	3.1
Total ($M)	19.6	19.3	20.1	19.8
Manning				
CONUS full time				
JEIM/CIRF	224	180	284	240
Dispatch team	11	21	11	21
CONUS part time	23	57	13	47
OCONUS full time	50	50	0	0
Mean transport pipeline				
CONUS	1.7	2.7	1.7	2.7
OCONUS	6.8	6.8	9.5	9.5

F110 Engine

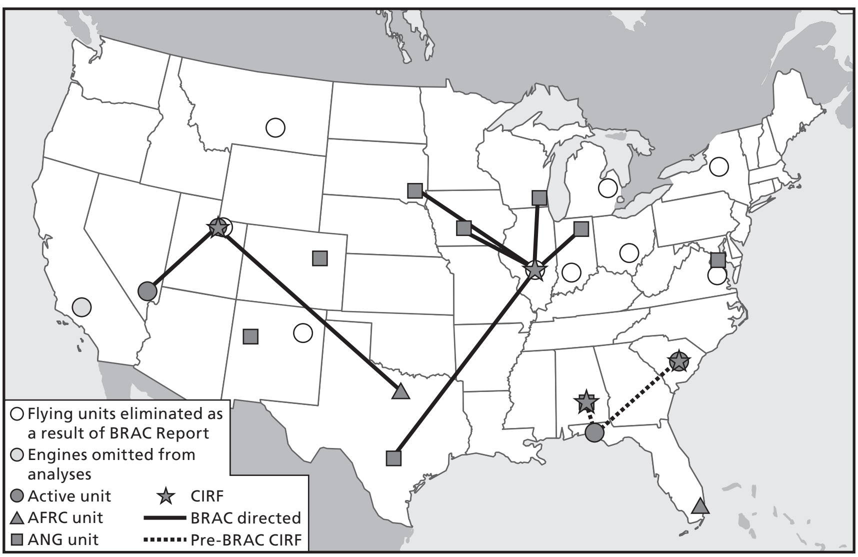
The F110 engine is used in the F-16, one engine powering each aircraft. There are two primary models of F110 engine, the F110-100 and F110-129. Post-BRAC, 16 CONUS flying units will operate this engine.[10] The BRAC Report designates two F110 CIRFs. Capital ANG (Illinois) loses its F-16 flying unit but becomes a CIRF, sup-

[10] As noted earlier, AFMC aircraft at Hill and Edwards AFBs were excluded from this analysis because of these units' special engine testing mission.

porting Lackland ANG (Texas), Joe Foss ANG (South Dakota), Truax ANG (Wisconsin), Fort Wayne ANG (Indiana), and Des Moines ANG (Iowa). Hill AFB (Utah) operates a CIRF supporting Nellis AFB (Nevada) and Fort Worth-Carswell AFRC (Texas). Some F110 CIRF structure existed prior to the BRAC deliberations. Eglin AFB had its F110-100 JEIM performed at Dannelly Field ANG (Alabama); Shaw AFB provided JEIM support for Eglin AFB F110-129 engines. The BRAC Report does not specify any actions regarding the CIRF arrangements at Dannelly Field ANG or Shaw AFB. Thus, the Dannelly Field ANG and Shaw AFB CIRF arrangements are not assumed to be fixed by the BRAC Report and may potentially be realigned in this analysis.

Figure C.5 presents a map of the units using the F110 engine. The unshaded circles represent flying units eliminated as a result of the BRAC Report. The light gray circle representing Edwards AFB is intended

Figure C.5
F110: Post-BRAC Network



RAND *MG418-C.5*

to indicate that these AFMC aircraft have been excluded from this analysis. All lines denote F110-100 engine assignments except for the dashed line connecting Eglin AFB and Shaw AFB, which denotes an F110-129 assignment (Shaw, Eglin, and Edwards AFBs are the only CONUS units operating the F110-129 post-BRAC).

Table C.4 presents further detail on the network of F110 bases. Locations considered for potential F110 CIRF sites include Capital

Table C.4
Post-BRAC F110 Operating Locations

		PAA	
Base Name	**MAJCOM**	**F110-100**	**F110-129**
Hill AFB (Utah)	ACC	72	0
Shaw AFB (South Carolina)	ACC	0	72
Nellis AFB (Nevada)	ACC	7	0
Eglin AFB (Florida)	AFMC/ACC[a]	2	6
Andrews ANG (Maryland)	ANG	18	0
Buckley ANG (Colorado)	ANG	18	0
Dannelly Field ANG (Alabama)	ANG	18	0
Des Moines ANG (Iowa)	ANG	18	0
Fort Wayne ANG (Indiana)	ANG	18	0
Joe Foss ANG (South Dakota)	ANG	18	0
Lackland ANG (Texas)	ANG	18	0
Kirtland ANG (New Mexico)	ANG	18	0
Truax ANG (Wisconsin)	ANG	18	0
Homestead AFRC (Florida)	AFRC	24	0
Fort Worth–Carswell AFRC (Texas)	AFRC	24	0

SOURCES: 2005 Defense Base Closure and Realignment Commission Report, 2005; data from AF/XPPE, 2005.

[a] Two F110-100 and one F110-129 at Eglin AFB are assigned to AFMC; five F110-129 at Eglin AFB are assigned to ACC.

ANG and all post-BRAC operating locations (including Edwards AFB) with the exception of Eglin AFB. No other potential CIRF locations were considered in this analysis.

F110: Deployment Scenario Data and Inputs

The total post-BRAC CONUS F110-100 PAA is 291, with 78 F110-129 PAA. The deployment scenario presented in Appendix B accounts for a deployment of 53 F110-100 and 14 F110-129 PAA. Under that scenario, the 53 F110-100–equipped aircraft deployed to three different FOLs, and the 14 F110-129–equipped aircraft deployed to another FOL.

Pre-BRAC, the CONUS totals were 371 F110-100 PAA and 96 F110-129 PAA. The pre-BRAC CONUS BSL spare engine allocations were 132 spare F110-100 engines and 28 spare F110-129 engines. The pre-BRAC total CONUS WRE allocations for F110-100s and F110-129s were 85 and 20 engines, respectively. Note that, prior to BRAC, OC-ALC classified the F110-100 as a constrained engine; its WRE computation was 111 engines.[11] Thus, no pre-BRAC spare engines were retired even though fleet size was reduced. Within this deployment scenario analysis, the CONUS WRE goals were each reduced by 20 percent to reflect the 20 percent of combat-coded PAA already deployed.

As with the TF34 analysis, transit times between bases were obtained using the DoD Standard Transit Time—Truckload (U.S. DoD, 2006), with two additional days added to each transit leg to allow for transit preparation time. The transport costs were again obtained from the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004) assuming an air-ride truck with expedited service and dual drivers for each shipment (these costs were presented earlier, in Table C.2). It was assumed that no engine pipeline or transit cost was encountered for engines receiving JEIM at their home-station bases. A five-day, one-way transit time from any FOL to an in-theater

[11] BSL engine inventories and WRE goals are from McIntosh, 2004a. As before, assets authorized to AFMC at Hill and Edwards AFBs are excluded.

OCONUS CIRF was assumed.[12] For transit between any FOL and any CONUS CIRF, a seven-day, one-way transit time was assumed. Note that OCONUS transit cost was not considered in this study.[13]

F110 failures are generally expressed in terms of an MTBF that is a function of engine operating hours. The Air Force PRS MTBF estimate is 196 hours per F110-100 removal and 332 hours per F110-129 removal (Strong, FY2005). To compute a base's engine induction rate into the JEIM for either engine type, one multiplies its corresponding number of PAA by its flying schedule (see Appendix B) and divides by the engine's MTBF. For this scenario, this implies a total mean daily failure rate, summed across both CONUS and deployed engines, of 1.87 F110-100 and 0.31 F110-129 engine failures per day.

Analysis indicated that 45 percent of JEIM inductions for each F110 engine type are classified as retained tasks, with an average duration of 51 hours per JEIM retained-task induction. The average duration of a non-retained-task JEIM induction was computed to be 270 hours for the F110-100 and 399 hours for the F110-129, with an additional eight hours spent at the test cell for each engine type (see discussion of data modeling in Appendix B). Note that this implies that F110-100 engines spend an average of 176 hours INW per JEIM induction, and F110-129 JEIM inductions require an average of 247 hours INW. CONUS JEIM shops were assumed to operate 24 hours per day, five days per week, requiring three eight-hour shifts per line and a 40-hour workweek per man. The OCONUS CIRF was assumed to operate 24 hours per day, seven days per week, with two daily shifts of 12 hours each and a 60-hour workweek per man. As with the TF34 analysis, maintenance manpower was adjusted using man-hour availability fac-

---

12 During the USAFE CIRF test, average one-way transit times of 4.3 to 4.8 days were observed for F110 engines (see HQ USAF, 2002).

13 OCONUS transport costs were not included because they are assumed to be constant: the distribution of OCONUS JEIM work between OCONUS CIRFs and CONUS CIRFs is predetermined, the FOL-OCONUS CIRF transport costs are not affected by the CONUS CIRF network design, and the transport cost from OCONUS is assumed not to vary greatly across different CONUS CIRF locations. However, estimates of potential OCONUS-CONUS transport costs are presented later in this appendix (see F110: Other Considerations, pp. 175–180).

tors, with additional management and support positions added to the requirement. No differentiation was made between “types” of full-time manpower (e.g., active duty versus ANG). It was assumed that OCONUS FOLs sent their retained task failures to the OCONUS CIRF, which would be staffed entirely by personnel deploying from the CONUS CIRFs. The remaining, more labor-intensive failures were sent to a CONUS CIRF in accordance with JEIM policy at the existing USAFE CIRF.

We assumed that F110-100 and F110-129 engines each required a dedicated rail team to perform JEIM but that test cell facilities were not dedicated to either engine type. Thus, a CIRF that maintained both engine types would need dedicated F110-100 rail teams and dedicated F110-129 rail teams, but its test cell would be capable of testing both engine types.

Any CONUS unit losing its JEIM capabilities through assignment to a CIRF was assumed to have its retained tasks performed on site. The only exception was Eglin AFB, which currently has its F110 JEIM performed off site; we assumed that Eglin must have its F110 JEIM performed at another location and would perform no retained tasks. The retained tasks were performed by a retained task team of five members, with one team required per CIRFed squadron. CONUS retained task teams were assumed to operate one shift of eight hours per day, five days per week, with a 40-hour workweek per man. OCONUS retained task teams required 12 manpower positions to staff operations of 24 hours by 7 days at the OCONUS CIRF. These personnel are in addition to the dispatch teams of three or four personnel per squadron (depending on squadron size) assigned to any reserve component squadron losing its JEIM capability.

The pre-BRAC manning at these units was obtained from UMDs and was determined to be 536 full-time positions, with 493 drill positions in the ANG and AFRC.[14] Note that 302 of these drill personnel are also counted within the 536 full-time positions, so 727 total F110 JEIM manpower personnel were available in CONUS to support contingency operations. Annual manning costs were again assumed to be

[14] Massey, 2004.

$60,000 per full-time position and $15,000 per drill position, giving a pre-BRAC annual manning cost of $39.6 million.

We again utilized the costs used in the TF34 analysis. The JEIM operating cost was defined as the associated personnel cost using a factor of $60,000 per man-year. The only CIRF setup cost considered was the cost required to obtain additional test cell equipment. This annualized cost of $1 million per additional CIRF test cell was only levied against new CIRF relationships; it was not incurred for bases performing only their own home-station repair. It was further assumed that no test cell setup cost would be incurred for any currently existing CIRF relationship (i.e., Eglin AFB F110-100 at Dannelly Field ANG, and Eglin AFB F110-129 at Shaw AFB). However, assignment of any additional supported units to an existing CIRF would cause the test cell setup cost to be incurred. OCONUS test cell costs were not considered in this analysis.

Recall that for the F110-100 and F110-129, the current CONUS BSL inventories are 132 and 28 spare engines, respectively, with total WRE allocations of 85 and 20 engines, respectively. Data obtained from OC-ALC indicate that the F110-100 has an average AWP of 5.0 percent of BSL spare engines (worldwide), and the F110-129 has an average of 6.6 percent AWP.[15] Because of the higher tempo of the deployed flying schedule, the AWP fraction was increased proportionally to the deployment scenario's increased failure rate when compared against the purely peacetime flying schedule. Multiplying this increased AWP value by the CONUS-wide spare engine pools gives a mean expectation of 10.9 AWP F110-100 and 3.0 AWP F110-129 engines. It was also assumed that the JEIM structure would have no effect on repair rates. Given the assumed repair rates, and accounting for the differences in CONUS and OCONUS work schedules and flying schedules, a total mean of 18.8 F110-100 and 4.4 F110-129 engines is expected INW across the CONUS and OCONUS CIRFs, independent of the CONUS JEIM network. Note that the OCONUS INT pipeline, containing a mean of 11.5 F110-100 and 1.9 F110-129 engines, is also independent of the CONUS JEIM structure. These

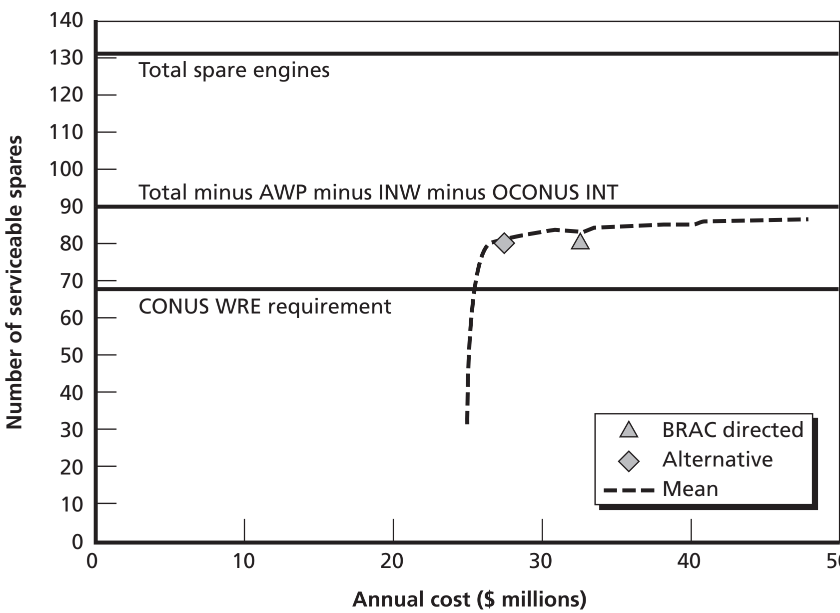
[15] McIntosh, 2005a–c.

considerations yield a maximum possible mean serviceable spare value of 91 F110-100 and 19 F110-129 engines (assuming zero engines AWM and zero engines in the CONUS transit pipeline).

F110: Deployment Scenario

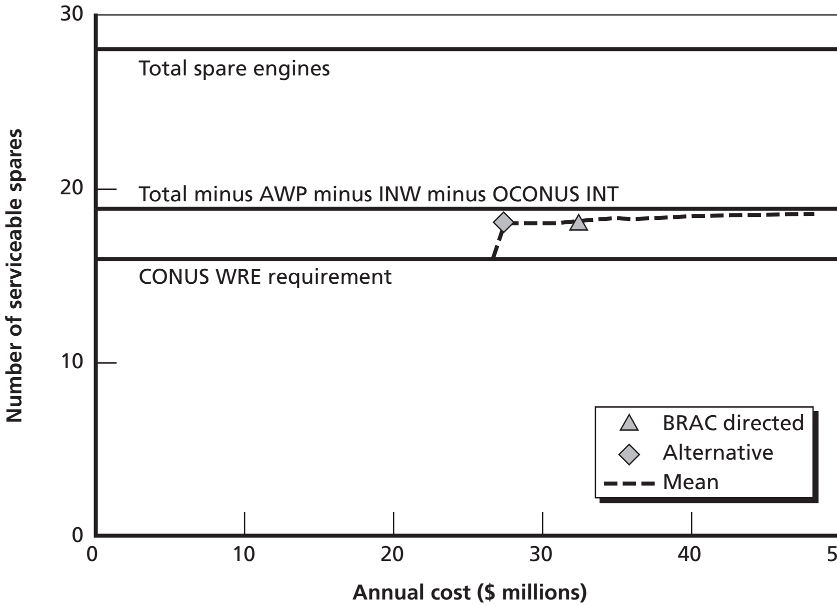
Figure C.6 presents the results of the deployment scenario analysis for the F110-100 JEIM structure, demonstrating the tradeoff between annual cost (transport cost, plus operating cost, plus annualized test cell setup cost) and number of serviceable spares available. Figure C.7 presents a similar graph for the F110-129. Note that the costs presented in each figure are those necessary to maintain the entire F110 engine pool and are not segregated by F110-100 or F110-129. The optimization model presented in Appendix A was used to identify the points

Figure C.6
F110-100 CIRF Network Options: Deployment Scenario



RAND *MG418-C.6*

Figure C.7
F110-129 CIRF Network Options: Deployment Scenario



RAND *MG418-C.7*

defining these curves, which demonstrate the best system performance (considering both engine types simultaneously) available for any level of expenditures. Note that each efficient frontier curve actually represents a very large number of potential solutions: For any point of interest along a curve (e.g., 80 serviceable F110-100 spares at a cost of $27 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the total combat-coded CONUS PAA, the serviceable spare levels can be kept above the residual WRE requirements.

Data obtained from OC-ALC indicate that, on average, net serviceable engines equal 48.5 percent of allocated F110-100 BSL engine inventories (worldwide),[16] with the F110-129 engine achieving 67.9 per-

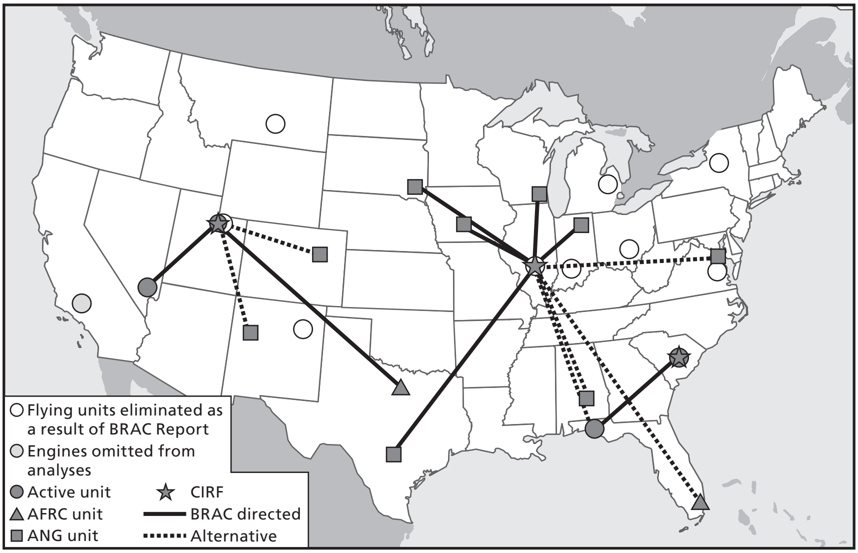
[16] C. R. McIntosh, Net Serviceable/Allocated BSL, January 2003 through November 2004, OC-ALC/LR, 2004b; McIntosh, 2005a,b.

cent of its BSL on this measure. Applying this rate to the CONUS-wide BSL allocation of 132 F110-100 engines implies that a mean of 64 net serviceable engines could be expected from the current CONUS JEIM network. Applying similar logic to the 28 F110-129 BSL engines results in a mean of 19 net serviceable engines. However, these data do not reflect the post-BRAC force structure. Moreover, the worldwide engine availability data do not reflect the same deployment flying schedule (this 23-month period includes support of OIF), making direct comparison with these results somewhat difficult. To provide a fairer basis for comparison, the post-BRAC F110 network presented in Figure C.5 was evaluated using the decision model; it produced 81 F110-100 and 18 F110-129 serviceable spare engines at a total cost of $32.6 million.

Rather than recommending any single network design as optimal, our analytic process identifies a set of alternative network designs lying along an efficient trade-space in which each identified network achieves the best possible weapon system support for its level of cost. For example, it is possible to identify a point on the efficient frontier curves of Figures C.6 and C.7 that achieves performance comparable to that of the post-BRAC network (81 F110-100 and 18 F110-129 serviceable spare engines) at a reduced cost of $27.4 million. The network configuration associated with this alternative solution is presented in Figure C.8. Note that both solutions maintain serviceable spares levels exceeding the residual WRE requirements of 68 F110-100 and 16 F110-129 engines. It is important to note that the curves appearing in Figures C.6 and C.7 are rather flat in the vicinity of the alternative solution, which suggests that alternative CONUS CIRF network designs can be identified that differ only slightly in performance but may be preferable for considerations outside the scope of this analysis.

The alternative CIRF network has a total full-time manpower requirement of 414, with a total manning of 271 at the CONUS CIRFs, 48 manpower positions at the OCONUS CIRF, 60 retained task team positions at the CIRFed units (excluding Eglin AFB, as discussed previously), and a total of 35 dispatch team positions at the 11 CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 504, with a total manning of

Figure C.8
F110: Alternative CIRF Network



RAND *MG418-C.8*

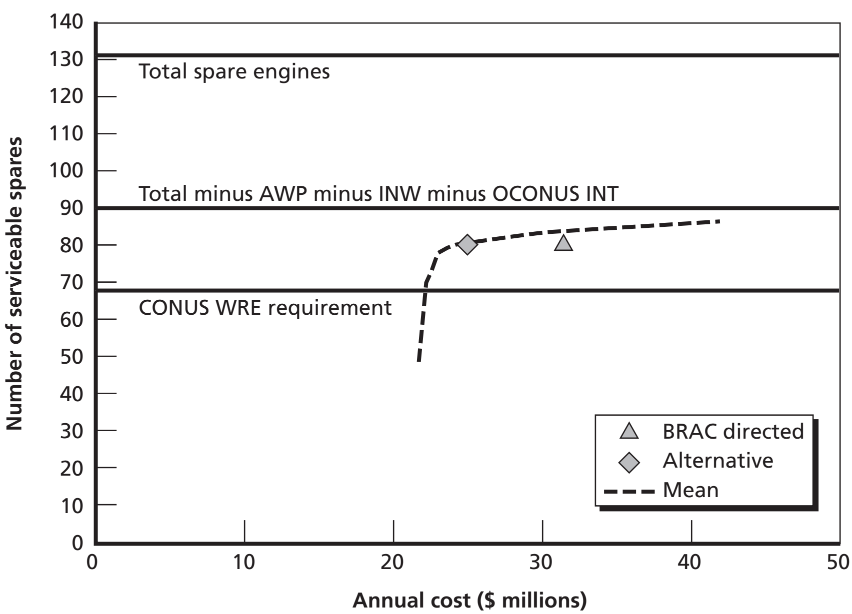
402 at the CONUS CIRFs/JEIM shops, 48 manpower positions at the OCONUS CIRF, 35 retained task team positions at the CIRFed units, and a total of 19 dispatch team positions at the six CIRFed reserve component units. Notice that the alternative solution requires 90 fewer full-time maintenance positions but requires increased transportation expenditures.

F110 Deployment Scenario: No Retained Tasks CONUS

In the previous section's analysis, a unit that loses its JEIM capabilities was given a retained task team. The motivation for using these teams is to allow failed engines requiring only a short maintenance action to be repaired on site, thereby eliminating transportation costs and pipelines for these engines. This retained task concept is currently used at OCONUS CIRFs, but the motivation is different in this case. Using OCONUS CIRFs to perform retained task maintenance actions for deployed aircraft allows for a reduced number of maintenance personnel deployed OCONUS compared with the manning requirement necessary if all JEIM is performed at the OCONUS CIRF. This policy also reduces the number of engines in the OCONUS-CONUS pipeline, reducing reliance on strategic airlift compared with the transport requirement necessary if all JEIM for deployed aircraft is performed in CONUS. However, these motivations do not apply to CONUS maintenance. Thus, an alternative maintenance policy was examined in which any CONUS unit losing its JEIM shop retained no tasks and thus needed no retained task team. The dispatch teams assigned to reserve component units were not affected by this policy. Also, OCONUS maintenance was not affected by this policy; OCONUS FOLs still sent their retained task failures to the OCONUS CIRF, with their remaining, more labor-intensive failures being sent to a CONUS CIRF.

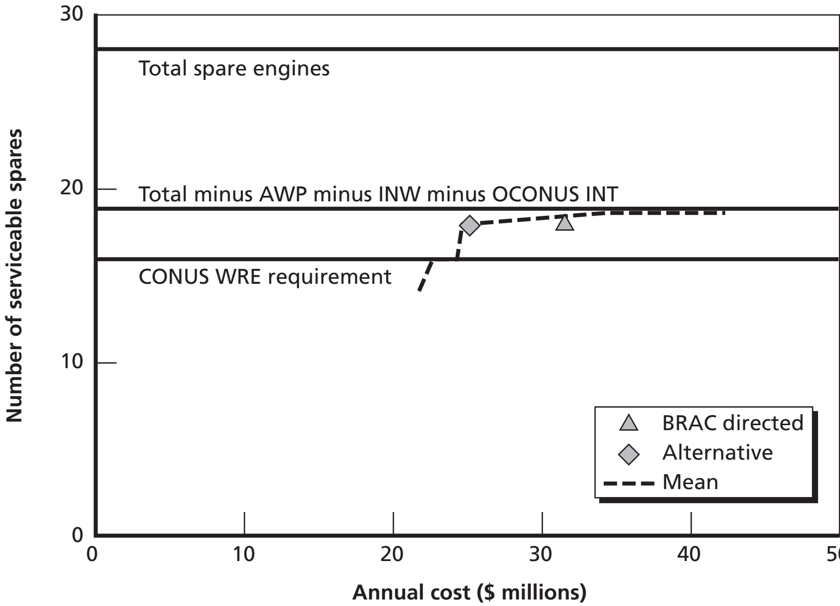
Figure C.9 shows the efficient frontier curve resulting from this alternative policy analysis for the F110-100 engine. Figure C.10 shows a similar graph for the F110-129. As before, costs shown in these figures

Figure C.9
F110-100 CIRF Network Options: No Retained Tasks CONUS



RAND *MG418-C.9*

Figure C.10
F110-129 CIRF Network Options: No Retained Tasks CONUS



RAND *MG418-C.10*

are those necessary to maintain the entire F110 engine pool and are not segregated by F110-100 or F110-129. The CONUS WRE requirements, as before, were reduced by 20 percent to reflect deployment of 20 percent of PAA. Note that the numbers of AWP and INW engines are unchanged under this alternative policy, as is the OCONUS INT pipeline. Thus, the maximum possible mean serviceable spare values are again 91 F110-100 and 19 F110-129 engines (assuming zero engines AWM and zero engines in the CONUS transit pipeline).

Note that the mean serviceable spare levels for this policy remain above the residual CONUS WRE requirements for most expenditure levels. Comparison of the post-BRAC network of Figure C.5 and the alternative network of Figure C.8 reveals that the two networks achieve similar performance (81 serviceable spare F110-100 engines and 18 serviceable spare F110-129 engines in each case) at comparable cost ($25.0 million for the alternative network versus $31.5 million for the post-BRAC network). The alternative CIRF network has a total full-time manpower requirement of 368, with a total manning of 285 at the CONUS CIRFs, 48 manpower positions at the OCONUS CIRF, and a total of 35 dispatch team positions at the 11 CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 483, with a total manning of 416 at the CONUS CIRFs/JEIM shops, 48 manpower positions at the OCONUS CIRF, and a total of 19 dispatch team positions at the six CIRFed reserve component units.

For both CIRF networks, the policy of no retained tasks CONUS achieves equal performance to the policy of retained tasks CONUS. However, the no retained tasks policy achieves significant savings in both total cost ($25.0 million versus $27.4 million for the alternative network, and $31.5 million versus $32.6 million for the post-BRAC network) and full-time manpower requirement (368 versus 414 for the alternative network, and 483 versus 504 for the post-BRAC network). Therefore, the policy of no retained tasks in CONUS is recommended for the F110 JEIM network.

It should be noted that CONUS CIRFed units have a workload associated with shipping and receiving engines to and from the CIRF. Although this work could reasonably be performed by the retained task teams or by the dispatch teams remaining at CIRFed reserve component units, it would constitute an additive workload for the remaining personnel at CIRFed active component units that do not have retained task teams. For the alternative CIRF network presented in Figure C.8 and the deployment scenario under consideration, the expected annual F110 shipping/receiving workloads are seven engines at Eglin AFB and 11 engines at Nellis AFB. Assuming two man-days for shipping preparation at the base and one man-day for receipt of engines from the CIRF, this annual workload equates to 21 man-days at Eglin AFB (approximately 0.08 man-year) and 33 man-days at Nellis AFB (approximately 0.13 man-year).

F110: Other Considerations

Recall that the retained task policy is currently used at OCONUS CIRFs to reduce the deployment burden on maintenance personnel (compared with a policy calling for all OCONUS JEIM to be performed in theater) and to reduce the requirement for OCONUS-CONUS transport of engines (compared with a policy that sends all OCONUS JEIM to CONUS). To investigate these policy effects, the CIRF network presented in Figure C.8 was tested against the deployment scenario using the recommended policy of no retained tasks in CONUS concurrent with an alternative policy in which the OCONUS CIRF performs JEIM for all OCONUS engine failures. This policy was determined to perform slightly better for the F110-100 engine (84 serviceable spares) and equally well for the F110-129 engine (18 serviceable spares) at a reduced cost of $22.6 million. This policy has a total full-time manpower requirement of 327, with a total manning of 175 at the CONUS CIRFs, 117 manpower positions at the OCONUS CIRF, and a total of 35 dispatch team positions at the 11 CIRFed reserve component units. Because OCONUS transportation costs are not included in this analysis, the cost differential between this policy and policy of retained tasks OCONUS ($22.6 million versus $25.0 million, respectively) is entirely attributable to the reduction in manpower positions from 368 to 327. Notice, however, the difference in deployment burden between the two policies. Assume that dispatch team positions are interchangeable with CIRF positions. The retained tasks OCONUS policy requires 48 manpower positions at an OCONUS CIRF, out of a total of 368 positions, requiring all full-time JEIM personnel to spend less than one-seventh of their time deployed OCONUS. The no retained tasks OCONUS policy requires 117 manpower positions at an OCONUS CIRF, out of a total of 327 positions, requiring all full-time JEIM personnel to spend more than one-third of their time deployed OCONUS. If the deployment burden is limited to a requirement that full-time JEIM personnel spend no more than one-fifth of their time deployed OCONUS, the no retained tasks OCONUS policy would require a total manning of 585 manpower positions, which is a significant increase over the 368-position requirement of the retained tasks OCONUS policy, with a still higher deployment burden (one-fifth versus one-seventh).

OCONUS maintenance policy also affects OCONUS-CONUS transportation requirements. This deployment scenario generates annual OCONUS failures of 344 F110-100 and 55 F110-129 engines. The policy of no retained tasks OCONUS would require no OCONUS-CONUS transport. Note, however, that every engine failure would require in-theater transport between the FOL and OCONUS CIRF. The policy of retained tasks OCONUS assumes that 45 percent of these failures would be retained at the OCONUS CIRF, generating an annual requirement of 189 F110-100 shipments and 30 F110-129 shipments (each way) between the FOLs and CONUS CIRFs. Each engine in this OCONUS-CONUS pipeline places a requirement on strategic airlift. As noted earlier, OCONUS transit cost was not modeled in this study; however, transit between FOLs and CONUS CIRFs is unlikely to be very costly. The cost to transport an F110-100 at the AMC channel rate between Dover AFB and Al Udeid (for example) is \$7,150 each way.[17] The retained tasks OCONUS policy would generate an associated annual OCONUS-CONUS transit cost of \$3.1 million. Note that this cost does not include transport between the OCONUS FOL and OCONUS CIRF. The key tradeoff occurs between these 438 OCONUS-CONUS shipments and the reduction in JEIM manpower deployment burden achieved through the policy of retained tasks OCONUS.

Other distinctions can be made between these two policies. An OCONUS CIRF operates a greater number of hours per week (168 hours, versus 120 at a CONUS CIRF), with deployed JEIM personnel working more hours per week (60 hours, versus 40). An expected savings of 2.4 F110-100s and 0.6 F110-129 at the CIRFs would be realized if all OCONUS JEIM were performed under the OCONUS CIRF's increased operating schedule. The policy of retained tasks OCONUS also requires an additional 2.1 F110-100s and 0.3 F110-129 for the OCONUS-CONUS transport pipeline for the two additional days INT each way for OCONUS-CONUS shipments. The policy of retained tasks OCONUS is able to offset a small number of these engines, however, because of decreases in AWM attributable to the larger facilities at CONUS CIRFs.

---

[17] F110-GE-100 dry weight is 3,920 lb (General Electric, 2007); AMC channel rate between Dover AFB and Al Udeid is \$1.824 per lb each way (U.S. Government, 2005).

If JEIM manpower is designed to support sustained deployment operations assuming shop operations of 24 hours per day, seven days per week, and a 60-hour workweek (as assumed at OCONUS CIRFs), little additional capacity is available to support more-stressing, surged operations. Note that the retained tasks OCONUS policy is able to perpetually sustain deployment operations using a workweek of three shifts by 40 hours at the CONUS CIRFs. This policy could provide additional support during surged operations through utilization of CONUS manning in a 60-hour workweek environment, potentially extending the capability of JEIM to support surged operations. Note that such considerations may also impact WRE requirement computations.

The MRC scenario presented in Appendix B was used to determine the part-time manning requirement necessary in the reserve component. Under this scenario, each theater receives a deployment of 132 F110-100–equipped PAA and 36 F110-129–equipped PAA. Because this MRC scenario is not assumed to be the perpetual condition for USAF forces, the effects of deployment burden receive less attention, and the minimization of strategic airlift receives priority, leading to an assumed policy wherein deployed aircraft receive all JEIM from their unique in-theater OCONUS CIRF. The CONUS residual aircraft receive JEIM from a CIRF at Nellis AFB (supporting itself, Eglin AFB, and Lackland ANG). The recommended policy of no retained tasks CONUS was assumed for the CONUS residual aircraft. The manpower requirements necessary to support this scenario were computed to be 57 positions in CONUS and 241 positions at each OCONUS CIRF, generating a total manpower requirement of 539 positions. The difference between these 539 positions and the 20 percent deployment scenario's manpower defines the part-time manning requirement.

The efficient frontier curves presented in Figures C.6 and C.7 and Figures C.9 and C.10 represent a very large number of potential solutions. Each point lying on these curves is associated with a specific CIRF network design. Table C.5 summarizes the maintenance, transportation, and equipment (annualized test cell setup) costs and the system performance and manpower requirements associated with

Table C.5
Cost and Performance: F110 CIRF Networks

	BRAC Directed		Alternative		
Retained tasks					
CONUS	Yes	No	Yes	No	No
OCONUS	Yes	Yes	Yes	Yes	No
Maintenance locations (CONUS/OCONUS)	8/1	8/1	3/1	3/1	3/1
Serviceable spares					
F110-100	81	81	81	81	84
F110-129	18	18	18	18	18
Payroll ($M)	30.8	29.8	26.7	24.6	22.8
Transportation ($M)	0.3	0.5	0.5	0.9	0.9
Test cell ($M)	2.1	2.1	2.1	2.1	2.1
Total ($M)	33.2	32.4	29.3	27.6	25.8
Manning					
CONUS full-time					
JEIM/CIRF	402	416	271	285	175
Retained task/ dispatch team	54	19	95	35	35
CONUS part-time	35	56	125	171	212
OCONUS full-time	48	48	48	48	117
Mean transport pipeline					
CONUS, F110-100	2.4	4.3	4.3	7.8	7.8
CONUS, F110-129	0.2	0.2	0.2	0.2	0.2
OCONUS, F110-100	11.5	11.5	11.5	11.5	9.4
OCONUS, F110-129	1.9	1.9	1.9	1.9	1.5

the 20 percent deployment scenario for the post-BRAC and alternative CIRF networks for all policies considered. Note that the part-time manning requirement necessary to support a large-scale MRC deployment is also included.

It should be noted that the total CONUS F110 WRE requirements are 85 F110-100s and 20 F110-129s, although the F110-100 is classified as a constrained engine with a WRE computation of 111 engines. Because the test scenario assumes that 20 percent of the combat-coded aircraft are deployed, it is assumed that the WRE requirements can also be reduced by 20 percent, giving residual WRE requirements of 68 F110-100s and 16 F110-129s (89 F110-100s, if considering the WRE computation). Note that the alternative CIRF solution (along with other solutions lying on the curves) exceeds the required performance for all policies considered in support of perpetually sustained deployment operations. These results indicate that a small number of F110 CIRFs can provide a cost-effective solution while attaining acceptable performance.

F100 Engine

The F100 engine is used in both the F-15 and F-16, with multiple series of F100 engines powering different aircraft. Table C.6 presents details on which engine series are used with which MDS.

Table C.6
F100 Engine Series

Engine Series	MDS
F100-100	F-15A/B/C/D
F100-220A/E	F-15A/B/C/D
F100-220B/F	F-16A/B/C/D
F100-220C/D	F-15E
F100-229A	F-15E
F100-229B	F-16C/D

SOURCE: C. R. McIntosh, RAND F100.ppt briefing, OC-ALC/LR, 2004c.

The F100-100 engine, the oldest of these engine series, was designed for the original F-15A/B. The F100-220E is an F100-100 that has been upgraded to achieve performance equivalent to that of the F100-220A series. The F100-220F and -220D are similarly upgraded engines, with performance equivalent to that of the F100-220B and -220C, respectively. A single engine powers all F-16 aircraft; two engines power all F-15 aircraft.

Post-BRAC, 22 CONUS flying units will operate this engine.[18] The BRAC Report designates two F100 CIRFs. Seymour-Johnson AFB will operate a CIRF supporting Langley AFB; New Orleans ANG (Louisiana) will operate a CIRF supporting Tyndall AFB and Jacksonville ANG (Florida). No F100 CIRF structure existed prior to the BRAC deliberations. Figure C.11 is a map of the units using the F100 engine. The uncolored circles represent flying units eliminated as a result of the BRAC Report. The light gray circle representing Edwards AFB indicates that these AFMC aircraft have been excluded from this analysis.

Table C.7 presents further detail on the network of F100 bases. Locations considered for potential F100 CIRF sites include all post-BRAC operating locations (excluding Edwards AFB). No other potential CIRF locations were considered in this analysis.

F100: Deployment Scenario Data and Inputs

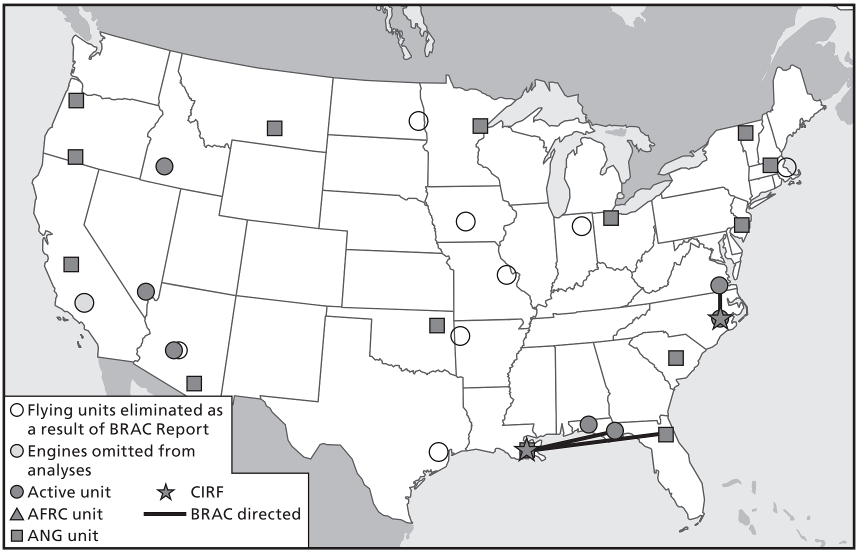
The BRAC Report recommendations for the F100 engine were influenced by a concurrent plan to reduce the overall size of the F-15A/B/C/D fleet. This reduction in fleet size involves retirement of the oldest aircraft and an upgrade in performance for older-model aircraft that are to be retained. The long-term plan for the fleet is to have only F-15C/Ds, all powered by F100-220A/E engines, which will require upgrades to the current engine fleet.[19] Cost data obtained from

---

[18] As noted earlier in this chapter, AFMC aircraft at Edwards AFB were excluded from this analysis because of this unit's special engine testing mission.

[19] Personal communication, Tom Smith, HQ ACC/A4MP, via email, December 16, 2005.

Figure C.11
F100: Post-BRAC Network



RAND *MG418-C.11*

Table C.7
Post-BRAC F100 Operating Locations

		PAA				
		F100-220			F100-229	
Base Name	MAJCOM	A/E	B/F	C/D	A	B
Mountain Home AFB	ACC			18	24	
Seymour-Johnson AFB	ACC			87		
Langley AFB	ACC	18				
Nellis AFB	ACC	39	8		10	17
Eglin AFB	AFMC/ACC[a]	8	8	3		
Tyndall AFB	AETC	48				

Table C.7—Continued

		PAA				
		F100-220			F100-229	
Base Name	**MAJCOM**	**A/E**	**B/F**	**C/D**	**A**	**B**
Luke AFB	AETC		114			
Jacksonville ANG (Florida)	ANG	18				
Portland ANG (Oregon)	ANG	18				
New Orleans ANG (Louisiana)	ANG	18				
Kingsley ANG (Oregon)	ANG	18				
Barnes ANG (Massachusetts)	ANG	18				
Great Falls ANG (Montana)	ANG	15				
Atlantic City ANG (New Jersey)	ANG		18			
Burlington ANG (Vermont)	ANG		18			
Fresno ANG (California)	ANG		18			
Toledo ANG (Ohio)	ANG		18			
Duluth ANG (Minnesota)	ANG		15			
Tulsa ANG (Oklahoma)	ANG		21			
Tucson ANG (Arizona)	ANG		62			
McEntire ANG (South Carolina)	ANG					24

SOURCES: BRAC Report, 2005; AF/XPPE, 2005.

[a] Four F100-220A/E, seven F100-220B/F, and two F100-220C/D at Eglin AFB are assigned to AFMC; four F100-220A/E, one F100-220B/F, and one F100-220C/D at Eglin AFB are assigned to ACC.

OC-ALC indicate that the total cost to upgrade an F100-100 into an F100-220E is $2.7 million.[20] The conversion cost of an F100-220B/F

[20] Personal communication, Janice Eberhard, OC-ALC/LR, via email, June 7, 2005.

to any of the F-15 engine series (F100-220A, C, D, or E) is minimal, requiring no additional equipment and fewer than eight man-hours.[21] Conversion from any of the F-15 F100-220 engine series to an F-16 engine series (F100-220B/F) requires procurement of a set of "turkey feathers" for the augmentor module.

The pre-BRAC total CONUS PAA was 279 F100-100, 33 F100-220A/E, 434 F100-220B/F, 90 F100-220C/D, 34 F100-229A, and 45 F100-229B. The post-BRAC total CONUS PAA, as presented in Table C.7, is 218 F100-220A/E, 300 F100-220B/F, 108 F100-220C/D, 34 F100-229A, and 41 F100-229B. The BRAC Report realigns the F100-220C/D–powered F-15E at Elmendorf AFB, assigning 18 PAA to Mountain Home AFB. The BRAC Report also realigns 24 of the 42 F100-220A/E-powered F-15C/D at Elmendorf AFB, distributing 18 PAA to Langley AFB and six PAA to an unspecified ANG unit.

Note that the F100-220A/E PAA is increased from 33 pre-BRAC to 218 post-BRAC because of the replacement of all F100-100 engines. As of December 2005, Jacksonville ANG had converted all of its 15 PAA to the F100-220A/E engine, and Portland ANG (Oregon) was converting its 15 PAA to the F100-220A/E engine.[22] Accounting for these 30 aircraft plus the 24 F100-220A/E PAA realigned from Elmendorf AFB, a shortfall of 131 F100-220A/E PAA remains. Note that the F100-200B/F PAA is reduced from 434 pre-BRAC to 300 post-BRAC. Because the conversion from F100-220B/F to F100-220A/E is extremely inexpensive, this analysis assumes that all 134 retiring F100-220B/F PAA will have their engines converted to F100-220A/E.[23] Because the F-15 requires two engines per aircraft, this action provides

---

[21] Personal communication, Tom Smith, HQ ACC/A4MP, via email, December 16, 2005.

[22] Personal communication, Tom Smith, HQ ACC/A4MP, via email, December 16, 2005.

[23] Note that retiring aircraft sent to the Aerospace Maintenance and Regeneration Center must be retired with an installed engine. The depot at Tinker AFB has F100-200 engines (used to power the original Block 10 and Block 15 F-16s) in storage. The plan is to retire F-16s with F100-200 engines installed and retain the F100-220B/F engines from the F-16s. Similarly, retiring F-15s will have F100-100 engines installed.

engines for 67 F100-220A/E PAA; however, it remains necessary to obtain engines for 64 F100-220A/E PAA.[24]

The deployment scenario presented in Appendix B accounts for a deployment of 21 F100-220A/E, 22 F100-220B/F, 13 F100-220C/D, five F100-229A, and five F100-229B–equipped aircraft. Under this scenario, all aircraft of a specific engine type deploy to a unique FOL.

The pre-BRAC CONUS BSL spare engine allocations were 181 F100-100, 11 F100-220A/E, 79 F100-220B/F, 35 F100-220C/D, 12 F100-229A, and 15 F100-229B engines. The pre-BRAC total CONUS WRE allocations were 95 F100-100, three F100-220A/E, 26 F100-220B/F, 24 F100-220C/D, two F100-229A, and nine F100-229B engines. Because of the BRAC Report's realignment of all F-15E at Elmendorf AFB to CONUS units, Elmendorf's F100-220C/D 23 BSL and 20 WRE engines were added to the post-BRAC CONUS F100-220C/D levels, resulting in post-BRAC allocations of 58 BSL and 44 WRE engines. Because the total PAA for the F100-229A was unaffected by the BRAC Report, and since there were only minor changes to the total F100-229B PAA (four PAA moved to backup inventory), WRE and BSL allocations for these two engines remain unchanged post-BRAC.

However, the F100-220A/E and F100-220B/F CONUS fleet sizes were modified significantly as a result of the BRAC Report. To obtain post-BRAC engine allocations, this analysis maintained the pre-BRAC ratios of BSL to PAA, applied to the post-BRAC PAA, for each engine series. The F100-220A/E had a BSL of 11 engines allocated against 33 PAA, resulting in a BSL of 73 engines when applied against its 218 PAA post-BRAC. The F100-220B/F had a BSL of 79 engines allocated against 434 PAA, resulting in a BSL of 55 engines when applied against its 300 PAA post-BRAC.

Post-BRAC WRE allocations were determined via comparison with pre-BRAC allocations at similarly sized units. For the

[24] Some of these engines could be obtained if the OCONUS F-15C/D fleet is reduced. While this action is outside the purview of BRAC, a total of 72 F-15C/D PAA are currently assigned to Lakenheath and Kadena ABs; these aircraft might be realigned in the upcoming Quadrennial Defense Review.

F100-220A/E, combat-coded units with 15 or 18 PAA were allocated three WRE each, according to the pre-BRAC WRE allocations at Mountain Home AFB (18 PAA) and Hickam ANG (15 PAA, at Hawaii). The non-combat-coded units at Tyndall AFB and Kingsley ANG (Oregon) were given WRE allocations based on their pre-BRAC F100-100 allocations, with two WRE at Tyndall AFB reflecting its decrease from 61 to 48 PAA, and one WRE at Kingsley ANG. The resulting total post-BRAC F100-220A/E WRE allocation is 21 engines. For the F100-220B/F, the combat-coded unit at Duluth ANG (15 PAA, at Minnesota) was allocated two WRE, according to the pre-BRAC WRE allocations at the 11 combat-coded 15-PAA ANG units. The remaining combat-coded units with 18 PAA or 21 PAA were allocated three WRE each. The non-combat-coded unit at Tucson ANG, which was unaffected by the BRAC Report, maintained its pre-BRAC allocation of four WRE. The resulting total post-BRAC F100-220B/F WRE allocation is 21 engines.

Note that prior to BRAC, OC-ALC classified all F100-220 series as constrained engines, with WRE computations of seven F100-220A/E, 32 F100-220B/F, and 27 F100-220C/D engines.[25] The F100-100 engine was also classified as a constrained engine, with a WRE computation of 195. Table C.8 contains the post-BRAC total CONUS BSL and WRE allocations assumed for this study. Within this deployment scenario analysis, the CONUS WRE goals were each reduced by 20 percent to reflect the 20 percent of combat-coded PAA already deployed.

As with the previous engine analyses, the transit times between bases were obtained using the DOD Standard Transit Time—Truckload (U.S. DoD, 2006), with two additional days added to each transit leg to allow for transit preparation time. The transport costs were again obtained from the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004) assuming an air-ride truck with

[25] BSL engine inventories and WRE goals are from C. R. McIntosh, FY04 F100F110TF34 BSL Goals CA CONUS.xls, OC-ALC/LR, August 30, 2004a. As before, assets authorized to AFMC at Edwards AFB were excluded.

Table C.8
Post-BRAC Total CONUS BSL and WRE Allocations for F100 Engine Series

Engine Series	Total CONUS BSL	Total CONUS WRE
F100-220A/E	73	21
F100-220B/F	55	21
F100-220C/D	58	44
F100-229A	12	2
F100-229B	15	9

SOURCE: C. R. McIntosh, RAND F100.ppt briefing, OC-ALC/LR, 2004c.

expedited service and dual drivers for each shipment (these costs are presented above, in Table C.2). It was assumed that no engine pipeline or transit cost was encountered for engines receiving JEIM at their home-station bases. A five-day one-way transit time from any FOL to an in-theater OCONUS CIRF was assumed,[26] and transit between any FOL and any CONUS CIRF was assumed to be seven days one way. Note that OCONUS transit cost was not considered in this study.[27]

F100 failures are generally expressed in terms of an MTBF that is a function of engine operating hours. The Air Force PRS MTBF estimate is 175 hours per F100-100 removal, 278 hours per F100-220A/E removal, 156 hours per F100-220B/F removal, 221 hours per F100-220C/D removal, 264 hours per F100-229A removal, and 231 hours per F100-229B removal (Strong, FY2005). Note that the assumption that all F100-100 engines will be retired or replaced by F100-220A/E engines results in a significant decrease in the engine

[26] During the USAFE CIRF test, average one-way transit times of 5.9 to 6.2 days were observed for F100 engines (see HQ USAF, 2002).

[27] OCONUS transport costs were not included because they were assumed to be constant: the distribution of OCONUS JEIM work between OCONUS CIRFs and CONUS CIRFs is predetermined, the FOL-OCONUS CIRF transport costs are not affected by the CONUS CIRF network design, and the transport cost from OCONUS is assumed not to vary greatly across different CONUS CIRF locations. However, estimates of OCONUS-CONUS transport costs are presented later in this appendix (see F100: Other Considerations, pp. 198–202).

failure rate for the F-15C/D fleet, beyond the effects of the reduction in PAA. This will generate a future reduced workload, along with an increased number of serviceable spare engines. To compute a base's engine induction rate into the JEIM for any engine series, one multiplies its corresponding number of PAA by its flying schedule (see Appendix B) and divides by the engine's MTBF. The resulting value should be multiplied by two for the F-15 engine series, since there are two engines per F-15. For this scenario, this implies a total mean daily failure rate, summed across both CONUS and deployed engines, of 1.46 F100-220A/E, 1.85 F100-220B/F, 1.04 F100-220C/D, 0.29 F100-229A, and 0.19 F100-229B engine failures per day.

Unlike the failure processes for engines, which were modeled according to engine series (e.g., F100-220A/E versus F100-220B/F), the maintenance of F100 engines was modeled according to engine families (F100-220 versus F100-229); see the data modeling section of Appendix B. All engine performance in the remainder of this section is thus presented by the F100-220 or F100-229 engine family, using the sum across all engine series within either engine family. Analysis indicated that 66 percent of F100-220 JEIM inductions and 54 percent of F100-229 JEIM inductions are classified as retained tasks. For both cases, analysis indicated an average duration of 61 hours per JEIM retained task induction. The average duration of a non-retained-task JEIM induction was computed to be 121 hours for the F100-220 and 85 hours for the F100-229, with an additional 15 hours spent at the test cell for each engine type (see discussion of data modeling in Appendix B). This implies that F100-220 engines spend an average of 86 hours INW per JEIM induction, and F100-229 JEIM inductions require an average of 79 hours INW. CONUS JEIM shops were assumed to operate 24 hours per day, five days per week, requiring three eight-hour shifts per line and a 40-hour workweek per man. The OCONUS CIRF was assumed to operate 24 hours per day, seven days per week, with two daily shifts of 12 hours each and a 60-hour workweek per man. As with the previous engine analyses, maintenance manpower was adjusted using man-hour availability factors, with additional management and support positions added to the requirement. No differentiation was made between "types" of full-time manpower (e.g., active duty versus ANG). It was assumed that OCONUS FOLs sent their retained task failures to the OCONUS CIRF, which would be staffed entirely by personnel deploying from the CONUS CIRFs. The remaining, more labor-intensive failures were sent to a CONUS CIRF in accordance with F110 JEIM policy at the existing USAFE CIRF.

It was assumed that the F100-220 and F100-229 engine families each required a dedicated rail team to perform JEIM and that the test cell facilities were not dedicated to either engine type. Thus, a CIRF that maintained both engine families would need dedicated F100-220 rail teams and dedicated F100-229 rail teams, but its test cell would be capable of testing both engine types. Note the assumption that an F100-220 rail team could repair any F100-220 family engine (F100-220A/E, F100-220B/F, or F100-220C/D); similarly, an F100-229 rail team could repair any F100-229 family engine (F100-229A or F100-229B).

Any CONUS unit losing its JEIM capabilities through assignment to a CIRF was assumed to have its retained tasks performed on site. These retained tasks were performed by a retained task team of five members, with either one or two teams required per CIRFed squadron depending on the retained workload at the squadron. CONUS retained task teams were assumed to operate one shift of eight hours per day, five days per week, with a 40-hour workweek per man. OCONUS retained task teams required 12 manpower positions to staff a team for operations of 24 hours by seven days at the OCONUS CIRF. These personnel are in addition to the dispatch teams of three or four personnel per squadron (depending on squadron size) assigned to any reserve component squadron losing its JEIM capability.

The pre-BRAC manning at these units was obtained from UMDs and determined to be 1,343 full-time positions (including 86 contractor field team personnel at ACC units), with 697 drill positions in the ANG and AFRC.[28] Note that 419 of these drill personnel are also counted within the 1,343 full-time positions, so 1,621 total F100 JEIM manpower personnel were available in CONUS to support con-

28 Massey, 2004.

tingency operations. Annual manning costs were again assumed to be $60,000 per full-time position and $15,000 per drill position, giving a pre-BRAC annual manning cost of $91.0 million.

We used the same costs as in the previous engine analyses. JEIM operating cost was defined as the associated personnel cost using a factor of $60,000 per man-year. The only CIRF setup cost considered was the cost required to obtain additional test cell equipment. This annualized cost of $1 million per additional CIRF test cell was levied against all CIRF relationships because the F100 engine does not have any currently existing CIRF relationships. This cost was not incurred for bases performing only their own home-station repair. OCONUS test cell costs were not considered in this analysis.

Recall that the post-BRAC BSL and WRE allocation values used in this study were derived in accordance with the changing F-15 and F-16 fleet sizes. Summing across each engine series within the two engine families, we found the post-BRAC total CONUS BSL allocations to be 186 F100-220s and 27 F100-229s, with WRE allocations of 86 F100-220s and 11 F100-229s. Data obtained from OC-ALC indicate that the F100-220 has an average AWP of 19.2 percent of BSL spare engines (worldwide), with an average of 9.7 percent AWP for the F100-229.[29] Because of the higher tempo of the deployed flying schedule, the AWP fraction was increased proportionally to the deployment scenario's increased failure rate when compared against the purely peacetime flying schedule. Multiplying this increased AWP value by the CONUS-wide spare engine pools gives a mean expectation of 46.3 AWP F100-220 and 3.7 AWP F100-229 engines. It was also assumed that the JEIM structure would have no effect on repair rates. Given the assumed repair rates and accounting for differences in CONUS and OCONUS work schedules and flying schedules, a total mean of 21.3 F100-220 and 2.1 F100-229 engines is expected INW across the CONUS and OCONUS CIRFs independent of the CONUS JEIM network. Note that the OCONUS INT pipeline, containing a mean of 14.7 F100-220 and 2.2 F100-229 engines, is also independent

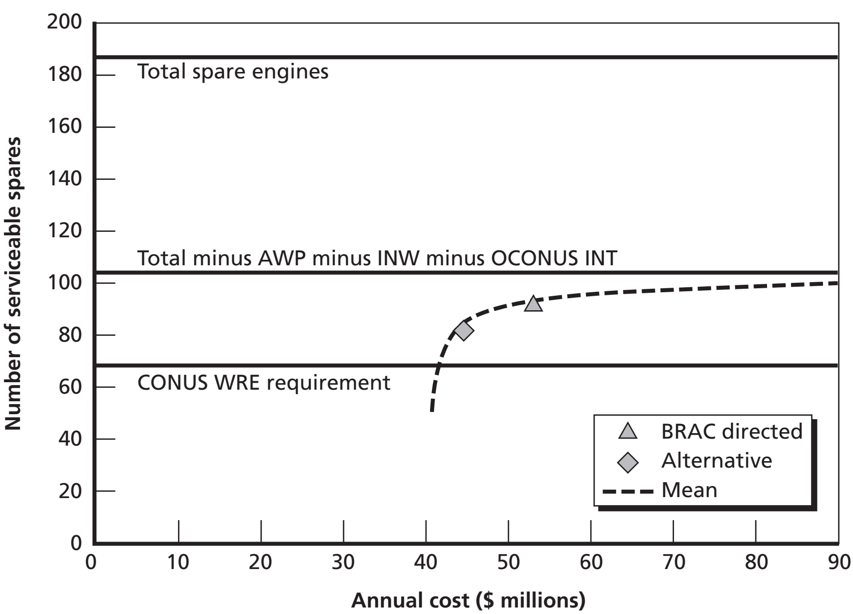
[29] McIntosh, 2005a,b; C. F. McIntosh, F100 WW ENMCS%, January 2003 through November 2004, OC-ALC/LR, 2005d.

of the CONUS JEIM structure. These considerations yield a maximum possible mean serviceable spare value of 104 F100-220 and 19 F100-229 engines (assuming zero engines AWM and zero engines in the CONUS transit pipeline).

F100: Deployment Scenario

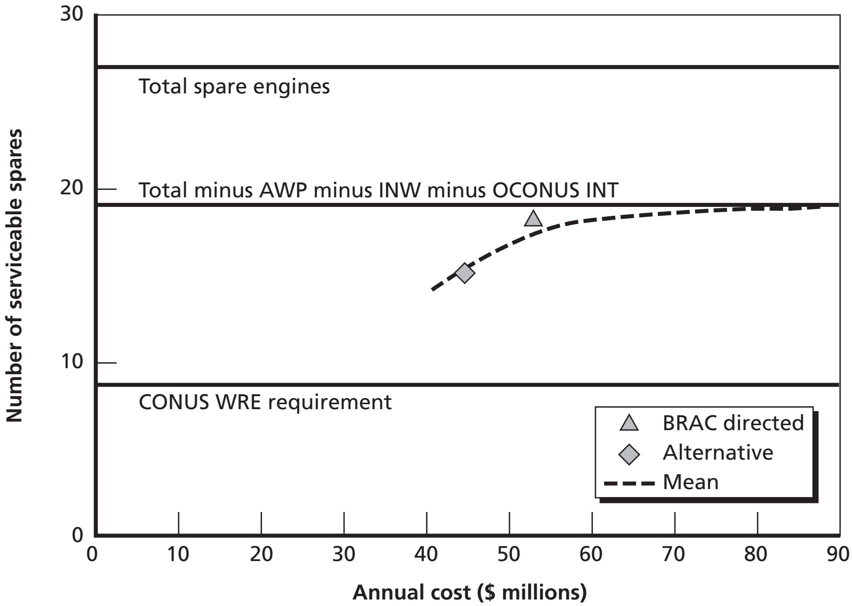
Figure C.12 presents the results of the deployment scenario analysis for the F100-220 JEIM structure, demonstrating the tradeoff between annual cost (transport cost, plus operating cost, plus annualized test cell setup cost) and number of serviceable spares available. Figure C.13 presents a similar graph for the F100-229. Note that costs presented in the figures are those necessary to maintain the entire F100 engine pool and are not segregated by F100-220 or F100-229. The optimization model presented in Appendix A was used to identify the points defining these curves, which demonstrate the best system performance

Figure C.12
F100-220 CIRF Network Options: Deployment Scenario



RAND *MG418-C.12*

Figure C.13
F100-229 CIRF Network Options: Deployment Scenario



RAND *MG418-C.13*

(considering both engine types simultaneously) available for any level of expenditures. Note that each efficient frontier curve actually represents a very large number of potential solutions: For any point of interest along a curve (e.g., 80 serviceable F100-220 spares at a cost of $43 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the total combat-coded CONUS PAA, the serviceable spare levels can be kept above the residual WRE requirements.

Data obtained from OC-ALC indicate that, on average, net serviceable engines equal 33.7 percent of allocated F100-220 BSL engine inventories (worldwide),[30] with the F100-229 engine achieving 59.6 percent of its BSL on this measure. Given the dramatic changes between the current and post-BRAC F100 fleets, it is difficult to compare the

---

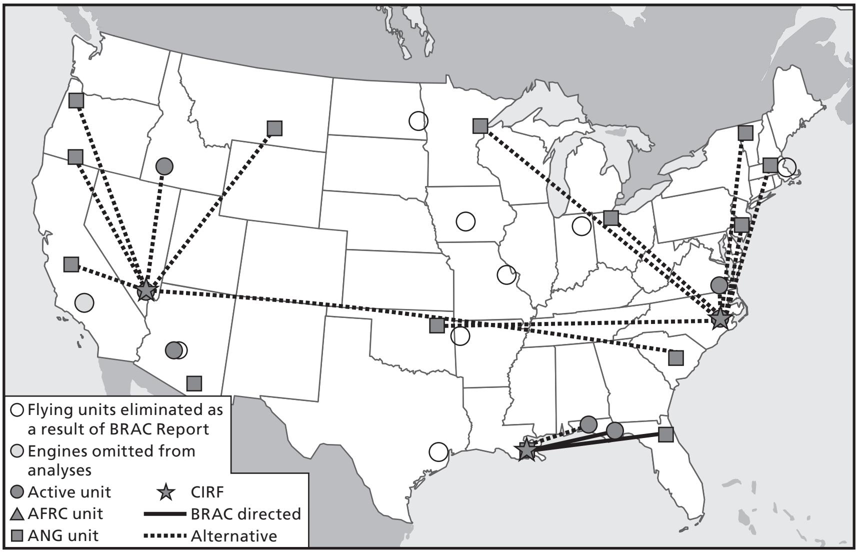
[30] McIntosh, 2004b, 2005a,b.

results presented in Figures C.12 and C.13 with historical data. To provide a fairer basis for comparison, the post-BRAC F100 network presented in Figure C.11 was evaluated using the decision model; it produced 92 F100-220 and 18 F100-229 serviceable spare engines at a total cost of $53.0 million.

Rather than recommending any single network design as optimal, our analytic process identifies a set of alternative network designs lying along an efficient trade-space in which each identified network achieves the best possible weapon system support for its level of cost. Note that this post-BRAC network lies very near to both efficient frontier curves. In fact, it lies slightly above the efficient frontier curve for Figure C.13. This seemingly inconsistent result occurs because the post-BRAC network point lies slightly below the efficient frontier curve for the larger pool of F100-220 engines presented in Figure C.12. Recall that the costs presented in Figures C.12 and C.13 are those necessary to maintain the entire F100 engine pool—the efficient frontier curves represent the best possible performance achievable for the entire F100 engine pool for any given level of expenditures.

Although it is not possible to achieve better performance than the post-BRAC solution for $53.0 million, this solution greatly exceeds the residual WRE requirements for each engine family. It is possible to identify a point on the efficient frontier curves of Figures C.12 and C.13 that achieves very good performance (82 F100-220 and 15 F100-229 serviceable spare engines) at a significantly reduced cost of $44.4 million. The network configuration associated with this alternative solution is presented in Figure C.14. Note that two units, Luke AFB and Tucson ANG, are not linked to any CIRF; instead, they maintain their home-station JEIM repair shops. These are both large bases, with 114 PAA at Luke AFB and 62 PAA at Tucson ANG. If either base were to assign its JEIM to an off-site CIRF, a large transportation cost would be incurred because of the base's large demand. However, this cost could not be offset with reductions in maintenance manpower since each base is already achieving significant economies of scale stemming from its large size. Note that both solutions maintain serviceable spares levels exceeding the residual WRE requirements of 69 F100-220 and nine F100-229 engines.

Figure C.14
F100: Alternative CIRF Network



RAND *MG418-C.14*

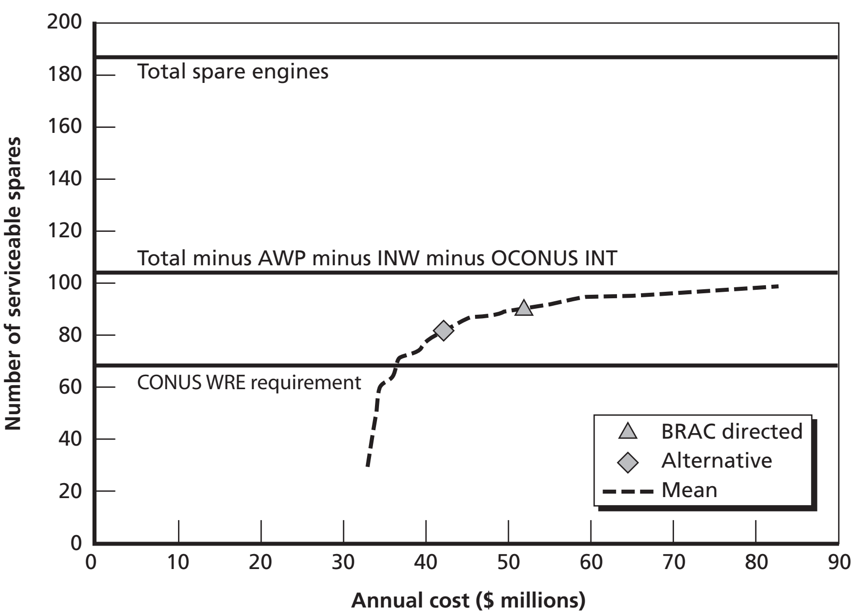
The alternative CIRF network has a total full-time manpower requirement of 678, with a total manning of 403 at the CONUS CIRFs/JEIM shops, 72 manpower positions at the OCONUS CIRF, 165 retained task team positions at the CIRFed units, and a total of 38 dispatch team positions at the 12 CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 847, with a total manning of 737 at the CONUS CIRFs/JEIM shops, 72 manpower positions at the OCONUS CIRF, 35 retained task team positions at the CIRFed units, and three dispatch team positions at Jacksonville ANG. Notice that the alternative solution requires 169 fewer full-time maintenance positions but requires greater expenditures for additional transportation along with a test cell setup cost at the Nellis AFB CIRF.

F100 Deployment Scenario: No Retained Tasks CONUS

In the previous section's analysis, a unit that loses its JEIM capabilities was given a retained task team. The motivation for using these teams is to allow failed engines requiring only a short maintenance action to be repaired on site, thereby eliminating the transportation costs and pipelines for these engines. The F110 analysis presented a contrast between the OCONUS and CONUS motivations for such a policy. As with the F110 analysis, an alternative maintenance policy was examined for the F100, in which any CONUS unit losing its JEIM shop retained no tasks and thus needed no retained task team. The dispatch teams assigned to reserve component units were not affected by this policy. Also, OCONUS maintenance was not affected by this policy; OCONUS FOLs still sent their retained task failures to the OCONUS CIRF and sent their remaining, more labor-intensive failures to a CONUS CIRF.

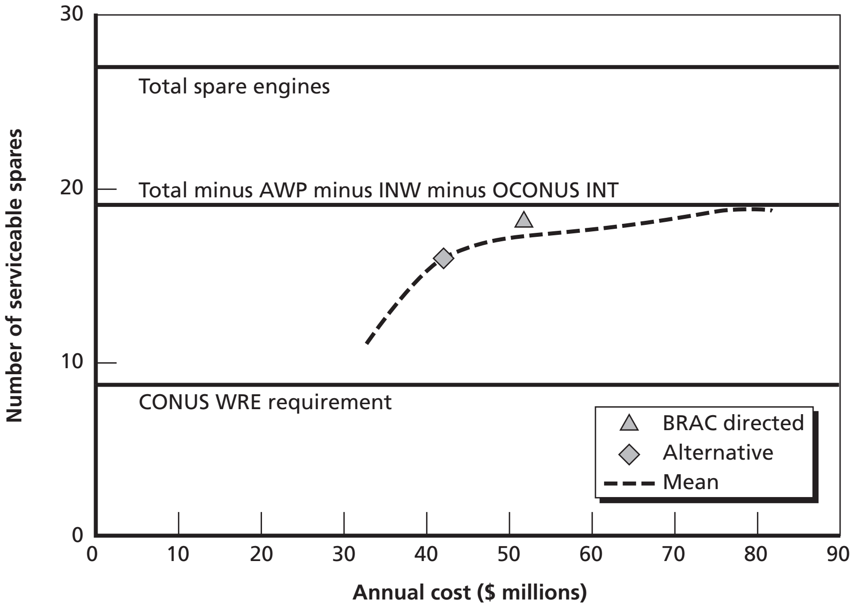
Figure C.15 presents the efficient frontier curve resulting from this alternative policy analysis for the F100-220 engine. Figure C.16 presents a similar graph for the F100-229. As before, costs presented in these figures are those necessary to maintain the entire F100 engine

Figure C.15
F100-220 CIRF Network Options: No Retained Tasks CONUS



RAND *MG418-C.15*

Figure C.16
F100-229 CIRF Network Options: No Retained Tasks CONUS



RAND *MG418-C.16*

pool and are not segregated by F100-220 or F100-229. The CONUS WRE requirements, as before, were reduced by 20 percent to reflect the deployment of 20 percent of PAA. Note that the numbers of AWP and INW engines are unchanged under this alternative policy, as is the OCONUS INT pipeline. Thus, the maximum possible mean serviceable spare value is again 104 F100-220 and 19 F100-229 engines (assuming zero engines AWM and zero engines in the CONUS transit pipeline).

Note that the mean serviceable spare levels for this policy remain above the residual CONUS WRE requirements for most expenditure levels. Comparison of the post-BRAC network of Figure C.11 and the alternative network of Figure C.14 reveals that both solutions again lie on the efficient frontier curves, with both solutions exceeding the residual WRE requirement (90 serviceable spare F100-220 and 18 serviceable spare F100-229 engines for the post-BRAC network, and 82 serviceable spare F100-220 and 16 serviceable spare F100-229 engines for the alternative network) at significantly different costs ($42.4 million for the alternative network versus $51.7 million for the post-BRAC network). The alternative CIRF network has a total full-time manpower requirement of 591, with a total manning of 481 at the CONUS CIRFs/JEIM shops, 72 manpower positions at the OCONUS CIRF, and a total of 38 dispatch team positions at the 12 CIRFed reserve component units. The post-BRAC network has a total full-time manpower requirement of 824, with a total manning of 749 at the CONUS CIRFs/JEIM shops, 72 manpower positions at the OCONUS CIRF, and a total of three dispatch team positions at Jacksonville ANG.

For both CIRF networks, the policy of no retained tasks CONUS achieves comparable performance to the policy of retained tasks CONUS. However, the no retained tasks policy achieves considerable savings in both total cost ($42.4 million versus $44.4 million for the alternative network, and $51.7 million versus $53.0 million for the post-BRAC network) and full-time manpower requirement (591 versus 678 for the alternative network, and 824 versus 847 for the post-BRAC network). Therefore, the policy of no retained tasks in CONUS is recommended for the F100 JEIM network.

It should be noted that CONUS CIRFed units have a workload associated with shipping and receiving engines to and from the CIRF. While this work could reasonably be performed by the retained task teams or the dispatch teams remaining at CIRFed reserve component units, it would constitute an additive workload for the remaining personnel at CIRFed active component units that do not have retained task teams. For the alternative CIRF network presented in Figure C.14 and the deployment scenario under consideration, the expected annual F100 shipping/receiving workload ranges from 19 engines at Eglin AFB to 90 engines at Tyndall AFB. Assuming two man-days for shipping preparation at the base and one man-day for receipt of engines from the CIRF, this annual workload equates to 57 man-days at Eglin AFB (approximately 0.22 man-year) and 270 man-days at Tyndall AFB (approximately 1.04 man-years).

F100: Other Considerations

Recall that the retained task policy is currently used at F110 OCONUS CIRFs to reduce the deployment burden on maintenance personnel (compared with a policy in which all OCONUS JEIM is performed in theater) and to reduce the requirement for OCONUS-CONUS transport of engines (compared with a policy that sends all OCONUS JEIM to CONUS). To investigate these policy effects, the CIRF network presented in Figure C.14 was tested against the deployment scenario using the recommended policy of no retained tasks CONUS concurrent with an alternative policy in which the OCONUS CIRF performs JEIM for all OCONUS engine failures. This policy was determined to perform slightly better for the F100-220 engine (85 serviceable spares) and equally well for the F100-229 engine (16 serviceable spares) at a slightly reduced cost of \$42.1 million. This policy has a total full-time manpower requirement of 587, with a total manning of 419 at the CONUS CIRFs/JEIM shops, 130 manpower positions at the OCONUS CIRF, and a total of 38 dispatch team positions at the 12 CIRFed reserve component units. Because OCONUS transportation costs are not included in this analysis, the cost differential between this policy and the policy of retained tasks OCONUS (\$42.1 million versus \$42.4 million, respectively) is entirely attributable to the reduction in manpower positions from 591 to 587. Notice, however, the difference in deployment burden between the two policies. Assume that dispatch team positions are interchangeable with CIRF positions. The retained tasks OCONUS policy requires 72 manpower positions at an OCONUS CIRF, out of a total of 591 positions, requiring all full-time JEIM personnel to spend less than one-eighth of their time deployed OCONUS. The no retained tasks OCONUS policy requires 130 manpower positions at an OCONUS CIRF, out of a total of 587 positions, requiring all full-time JEIM personnel to spend more than one-fifth of their time deployed OCONUS. If the deployment burden is limited to a requirement that full-time JEIM personnel spend no more than one-fifth of their time deployed OCONUS, the no retained tasks policy would require a total manning of 650 manpower positions, a significant increase over the 591-position requirement of the retained tasks OCONUS policy, with a still higher deployment burden (one-fifth versus one-eighth). Note, however, that according to this analysis, the F100 engine is a better candidate than the F110 engine for a policy of no retained tasks OCONUS.

OCONUS maintenance policy also affects OCONUS-CONUS transportation requirements. This deployment scenario generates annual OCONUS failures of 473 F100-220 and 66 F100-229 engines. The policy of no retained tasks OCONUS would require no OCONUS-CONUS transport. Note, however, that every engine failure would require in-theater transport between the FOL and OCONUS CIRF. The policy of retained tasks OCONUS assumes that 66 percent of these F100-220 failures and 54 percent of these F100-229 failures would be retained at the OCONUS CIRF, generating an annual requirement of 161 F100-220 shipments and 31 F100-229 shipments (each way) between the FOLs and CONUS CIRFs. Each engine in this OCONUS-CONUS pipeline places a requirement on strategic airlift. Recall that OCONUS transit cost was not modeled in this study; however, transit between FOLs and CONUS CIRFs is unlikely to be very costly. The cost to transport an F100-220 at the AMC channel rate between Dover AFB and Al Udeid (for example) is $6,822 each way.[31] The policy of retained tasks OCONUS would generate an associated annual OCONUS-CONUS transit cost of $2.6 million. Note that this cost does not include OCONUS FOL–OCONUS CIRF transport. The key tradeoff occurs between these 384 OCONUS-CONUS shipments and the reduction in JEIM manpower deployment burden achieved through the policy of retained tasks OCONUS.

Other distinctions can be made between these policies of retained tasks and no retained tasks OCONUS. The OCONUS CIRF operates a greater number of hours per week (168 hours, versus 120 at a CONUS CIRF) with deployed JEIM personnel working more hours per week (60 hours, versus 40). An expected savings of 1.3 F100-220 and 0.1 F100-229 engines at the CIRFs would be realized if all OCONUS JEIM were performed under the OCONUS CIRF's increased operating schedule. The retained tasks OCONUS policy also requires an

[31] F100 weight is 3,740 lb (Pratt Witney, 2007); AMC channel rate between Dover AFB and Al Udeid is $1.824 per lb each way (U.S. Government, 2005).

additional 1.8 F100-220 and 0.3 F100-229 engines for the OCONUS-CONUS transport pipeline because of the two additional days INT each way for OCONUS-CONUS shipments.

If JEIM manpower is designed to support sustained deployment operations assuming 24 hours per day, seven days per week shop operations, and a 60-hour workweek (as assumed at OCONUS CIRFs), little additional capacity is available to support more-stressing, surged operations. Note that the retained tasks OCONUS policy is able to perpetually sustain deployment operations using a workweek of three shifts by 40 hours at the CONUS CIRFs. This policy could provide additional support during surged operations through the utilization of CONUS manning in a 60-hour workweek environment, potentially extending the capability of JEIM to support surged operations. Note that such considerations may also impact WRE requirement computations.

The MRC scenario presented in Appendix B was used to determine the part-time manning requirement necessary in the reserve component. Under this scenario, each theater receives a deployment of 53 F100-220A/E, 54 F100-220B/F, 33 F100-220C/D, 12 F100-229A, and 12 F100-229B–equipped aircraft. Because this MRC scenario is not assumed to be the perpetual condition for USAF forces, the effects of deployment burden receive less attention, and the minimization of strategic airlift receives priority, leading to an assumed policy wherein deployed aircraft receive all JEIM from their unique in-theater OCONUS CIRF. The CONUS residual aircraft receive JEIM from a CIRF at Seymour-Johnson AFB (supporting itself, Eglin AFB, and Tyndall AFB), along with a CIRF at Nellis AFB (supporting itself, Luke AFB, Kingsley ANG, and Tucson ANG). The recommended policy of no retained tasks CONUS was assumed for the CONUS residual aircraft. The manpower requirements necessary to support this scenario were computed to be 235 positions in CONUS and 253 positions at each OCONUS CIRF, generating a total manpower requirement of 741 positions. The difference between these 741 positions and the 20 percent deployment scenario's manpower defines the part-time manning requirement.

The efficient frontier curves presented in Figures C.12 and C.13 and Figures C.15 and C.16 represent a very large number of potential solutions. Each point lying on these curves is associated with a specific CIRF network design. Table C.9 summarizes the maintenance, transportation, and equipment (annualized test cell setup) costs and the system performance and manpower requirements associated with the 20 percent deployment scenario for the post-BRAC and alternative CIRF networks for all policies considered. Note that the part-time manning requirement necessary to support a large-scale MRC deployment is also included.

It should be noted that for the F100 engine, the total post-BRAC WRE requirements were estimated as 86 F100-220 and 11 F100-229 engines. Because the test scenario assumes that 20 percent of the combat-coded aircraft are deployed, it is assumed that the WRE requirements can also be reduced by 20 percent, giving residual WRE requirements of 69 F100-220 and nine F100-229 engines. Note that the alternative CIRF solution (along with other solutions lying on the curves) exceeds the required performance for all policies considered in support of perpetually sustained deployment operations. These results indicate that a small number of F100 CIRFs can provide a cost-effective solution while attaining acceptable performance.

Table C.9
Cost and Performance: F100 CIRF Networks

	BRAC Directed		Alternative		
Retained tasks					
CONUS	Yes	No	Yes	No	No
OCONUS	Yes	Yes	Yes	Yes	No
Maintenance locations (CONUS/OCONUS)	18/1	18/1	5/1	5/1	5/1
Serviceable spares					
F100-220	92	90	82	82	85
F100-229	18	18	15	16	16
Payroll ($M)	50.8	49.4	41.6	37.7	37.5
Transportation ($M)	0.1	0.2	0.6	1.7	1.7
Test cell ($M)	2.1	2.1	3.1	5.2	5.2
Total ($M)	53.0	51.7	45.4	44.6	44.5
Manning					
CONUS full-time					
JEIM/CIRF	737	749	403	481	419
Retained task/ dispatch team	38	3	203	38	38
CONUS part-time	0	0	63	150	154
OCONUS full-time	72	72	72	72	130
Mean transport pipeline					
CONUS, F100-220	1.8	5.2	5.3	15.6	15.6
CONUS, F100-229	0.0	0.0	1.2	2.7	2.7
OCONUS, F100-220	14.7	14.7	14.7	14.7	13.0
OCONUS, F100-229	2.2	2.2	2.2	2.2	1.8

NOTE: Columns may not sum because of rounding.

APPENDIX D

Detailed Results of ECM Pod Analyses

This appendix provides a detailed report of the CONUS CIRF analyses performed in support of the ALQ-184 and ALQ-131 ECM pods. A shortened version of these results is presented in Chapter Four; it discusses both the post-BRAC and the alternative CIRF ECM pod networks, including each network's cost and performance for each pod type, and describes in abbreviated form the detailed results for the ALQ-184. The purpose of this appendix is to document the data and analytic processes that were used to generate our findings for these pods.

The BRAC Report recommendations establish several CONUS CIRF relationships, all of which are assumed to be fixed in this analysis. We further assumed that additional supported units may potentially be added to BRAC-designated CIRFs.

ALQ-184 and ALQ-131

The ALQ-184 and ALQ-131 are self-protect ECM pods that are used on both A-10/OA-10 and F-16 aircraft. Currently, there are two versions of the ALQ-184 pod: the ALQ-184-Short and ALQ-184-Long. Because all ALQ-184-Short pods are being upgraded to ALQ-184-Long, this analysis considered all ALQ-184 pods to be the ALQ-184-Long version.

Pre-BRAC, the ALQ-131 pods assigned to AFRC units received an upgrade modification. These 49 pods were equipped with a MIL-STD-1553 data bus card. No other pods received this upgrade pre-BRAC, although there are plans to perform this upgrade on the entire fleet of ALQ-131 pods.[1] Because the AFRC paid for this card upgrade, we assumed that the 49 upgraded pods will be assigned to AFRC units post-BRAC.[2] Note that this upgrade impacts neither the pod's failure rate nor its repair. Thus, from a modeling standpoint, the upgraded ALQ-131 pods do not behave differently than do the other ALQ-131 pods. However, unlike other CIRF commodities for which common ownership has been assumed, the upgraded pods need to be tracked separately to ensure they return from the CIRF to an owning AFRC unit.

Post-BRAC, 22 CONUS flying units will operate the ALQ-184 pod and nine CONUS flying units will operate the ALQ-131 pod.[3] The BRAC Report designates one ALQ-184 CIRF relationship. Shaw AFB will operate an ALQ-184 CIRF supporting Moody AFB. The BRAC Report does not designate any ALQ-131 CIRF relationships. No CIRF structure existed for either the ALQ-184 or the ALQ-131 prior to the BRAC deliberations. Figure D.1 presents a map of the units using the ALQ-184 pod. Figure D.2 presents a map of the units using the ALQ-131 pod. The uncolored circles on these maps represent pod-equipped units eliminated as a result of the BRAC Report.

The ALQ-184 and ALQ-131 analyses were performed separately because no units under consideration operate both types of pod and each pod type requires its own electronic test stand—the AN/ALM233-D for the ALQ-184, and the AN/ALM-256 for the ALQ-131—for pod ILM. Thus, from a cost-benefit standpoint, it would not be efficient to perform both ALQ-184 and ALQ-131 pod ILM at any single site. It is preferable to perform ALQ-184 ILM at an ALQ-184 operating location and ALQ-131 ILM at an ALQ-131 operating location.

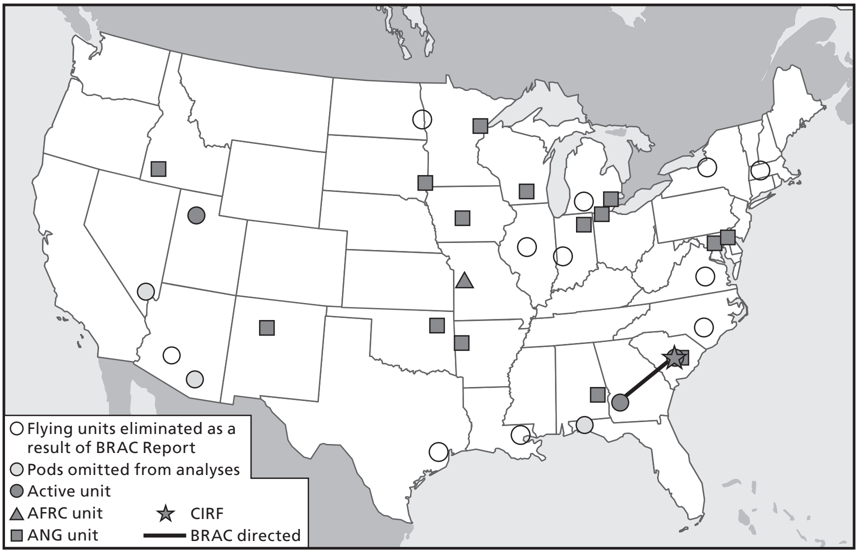
---

1 All ALQ-131 pods have been funded to be equipped with this upgrade during FY 2008 through FY 2009 (personal communication, Daniel Graham, ACC/A3IE, via email, February 14, 2007).

2 Personal communication, Daniel Graham, ACC/A3IE, via email, September 23, 2005.

3 Pods at Nellis AFB, Eglin AFB, and Tucson ANG were omitted from the ALQ-184 and ALQ-131 pod analyses because these units support pod testing requirements. These units appear as light gray circles in Figures D.1 and D.2.

Figure D.1
ALQ-184: Post-BRAC Network

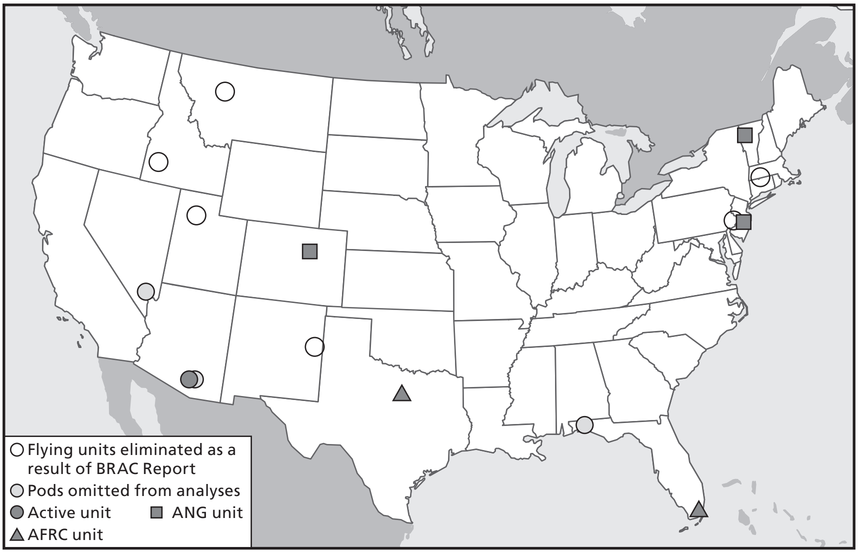


RAND *MG418-D.1*

Table D.1 presents further detail on the network of ALQ-184 and ALQ-131 bases. It was assumed that all pre-BRAC ALQ-184 and ALQ-131 units that retained either A-10/OA-10 or F-16 aircraft following implementation of the BRAC Report recommendations would also maintain an ECM pod assignment. Moody AFB was assumed to be the only new ALQ-184 unit. No new ALQ-131 units were considered. All post-BRAC ALQ-184 operating locations were considered for potential ALQ-184 CIRF sites. Similarly, all post-BRAC ALQ-131 operating locations were considered for potential ALQ-131 CIRF sites. No other potential CIRF locations were considered in these analyses.

Pre-BRAC, there were 623 ALQ-184 pods assigned to CONUS units in support of an associated 564 PAA (excluding Eglin AFB, Nellis AFB, and Tucson ANG). Post-BRAC, CONUS ALQ-184–equipped units have a total of 498 PAA. Pre-BRAC, there were 265 ALQ-131 pods assigned to CONUS units in support of an associated 237 PAA (excluding Eglin AFB, Nellis AFB, and Tucson ANG). Post-BRAC,

Figure D.2
ALQ-131: Post-BRAC Network



RAND *MG418-D.2*

Table D.1
Post-BRAC ALQ-184 and ALQ-131 Operating Locations

Base Name	MAJCOM	ECM Pod Type	Aircraft Type	PAA
Hill AFB (Utah)	ACC	ALQ-184	F-16	72
Moody AFB (Georgia)	ACC	ALQ-184	A-10/OA-10	48
Shaw AFB (South Carolina)	ACC	ALQ-184	F-16	72
Andrews ANG (Maryland)	ANG	ALQ-184	F-16	18
Boise ANG (Idaho)	ANG	ALQ-184	A-10/OA-10	18
Dannelly Field ANG (Alabama)	ANG	ALQ-184	F-16	18
Des Moines ANG (Iowa)	ANG	ALQ-184	F-16	18
Duluth ANG (Minnesota)	ANG	ALQ-184	F-16	15
Fort Smith ANG (Arkansas)	ANG	ALQ-184	A-10/OA-10	18

Table D.1—Continued

Base Name	MAJCOM	ECM Pod Type	Aircraft Type	PAA
Fort Wayne ANG (Indiana)	ANG	ALQ-184	F-16	18
Joe Foss ANG (South Dakota)	ANG	ALQ-184	F-16	18
Kirtland ANG (New Mexico)	ANG	ALQ-184	F-16	18
Martin State ANG (Maryland)	ANG	ALQ-184	A-10/OA-10	18
McEntire ANG (South Carolina)	ANG	ALQ-184	F-16	24
Selfridge ANG (Michigan)	ANG	ALQ-184	A-10/OA-10	24
Toledo ANG (Ohio)	ANG	ALQ-184	F-16	18
Truax ANG (Wisconsin)	ANG	ALQ-184	F-16	18
Tulsa ANG (Oklahoma)	ANG	ALQ-184	F-16	21
Whiteman AFRC (Missouri)	AFRC	ALQ-184	A-10/OA-10	24
Davis-Monthan AFB (Arizona)[a]	ACC	ALQ-131	A-10/OA-10	24
Atlantic City ANG (New Jersey)	ANG	ALQ-131	F-16	18
Buckley ANG (Colorado)	ANG	ALQ-131	F-16	18
Burlington ANG (Vermont)	ANG	ALQ-131	F-16	18
Homestead AFRC (Idaho)	AFRC	ALQ-131	F-16	24
Fort Worth-Carswell AFRC (Texas)	AFRC	ALQ-131	F-16	24

SOURCES: BRAC Report, 2005; AF/XPPE, 2005.

[a] This AFB has one combat-coded squadron of 24 PAA and two training squadrons with a combined PAA of 42. Since ALQ-131 pods are only assigned to combat-coded units, only the combat-coded squadron is presented.

CONUS ALQ-131–equipped units have a total of 126 PAA. Note that all ALQ-184 and ALQ-131 pods in this analysis are assigned to combat-coded squadrons.

The BRAC Report realigns the squadron of A-10/OA-10 aircraft at Eielson AFB to CONUS units but does not realign the F-16 squadron at Eielson AFB. Pre-BRAC, 40 ALQ-184 pods were assigned to Eielson AFB. Because Eielson AFB loses one-half of its fighter aircraft via BRAC recommendations, it was assumed that one-half of Eielson's

ALQ-184 pods would be reassigned, resulting in a total of 643 pods for potential assignment to these CONUS units.

Note that the total number of CONUS PAA supported by ALQ-184 pods decreases from 564 to 498 post-BRAC, with a similar decrease from 237 to 126 PAA for the ALQ-131. Thus, it is necessary to determine whether a post-BRAC requirement exists for all 643 ALQ-184 and 265 ALQ-131 pods.

ALQ-184 and ALQ-131: Deployment Pod Requirements Computation

Before the optimization procedure presented in Appendix A can be applied to the ALQ-184 and ALQ-131 networks, a deployment-based pod requirement must be computed for each ECM pod type. The 20 percent deployment scenario presented in Appendix B is straightforward in its implied number of combat-coded aircraft; however, the number of ECM pods that must deploy to support this number of aircraft is not readily apparent. The deployment-based pod requirement must satisfy the following objective: every deployed sortie must have an FMC ECM pod. Flying units need to deploy with spare pods beyond their PAA level to compensate for failed pods. Additional spare pods are needed at the ILM facility supporting the deployed unit to compensate for AWP shortages.

Determining a failure rate for ECM pods is somewhat difficult because pod use during peacetime training missions is limited. ECM pods cannot be fully turned on during most training missions because they interfere with civilian communications. Furthermore, it is difficult to determine whether a pod is working correctly in a non-threat environment because the pod's BIT performs poorly. Although a small number of pod failures are diagnosed during training missions, scheduled maintenance accounts for the majority of the ECM pod workload during peacetime. ALQ-184-Long pods have a PMI of 90 calendar days; ALQ-131 pods have a PMI of 180 calendar days. The data modeling section of Appendix B discusses an analysis we performed that indicated a mean pod failure rate of 0.0196 per ALQ-184 operating hour and 0.0098 per ALQ-131 operating hour. Note that most of these failures are delayed discrepancies during peacetime, which means the failure is not diagnosed until the pod's next scheduled maintenance action.

Assuming that the deployed pod utilization rate is 100 percent (i.e., ECM pods are used on every deployed sortie), daily pod failure rates can be computed for notional squadrons. Assume that deployed squadrons of 24 PAA support the deployment flying schedules presented in Appendix B. If ALQ-184–equipped aircraft are deployed, such an A-10 squadron will generate 1.176 ALQ-184 pod failures per day, and such an F-16 squadron will generate 1.646 ALQ-184 pod failures per day. If the deployment utilizes ALQ-131 pods, such an A-10 squadron will generate 0.588 ALQ-131 pod failures per day, and such an F-16 squadron will generate 0.823 ALQ-131 pod failures per day.

WR-ALC provided pod repair time data from the RAMPOD database.[4] A sample of 6,100 ALQ-184-Long maintenance actions indicated a mean repair time of 27.2 hours per ALQ-184-Long repair. A sample of 6,400 ALQ-131 maintenance actions indicated a mean repair time of 33.2 hours per ALQ-131 repair. It was assumed that the deployed aircraft would have their ECM pod ILM performed at an OCONUS CIRF staffed entirely by personnel deploying from the CONUS CIRFs. The USAFE CIRF test of September 2001 through February 2002 supported the ALQ-131 pod during both scheduled AEF rotations and OEF.[5] During this test, 60 pods were serviced at the CIRF, with averages of 1.0 days preparation time, 4.2 days inbound transit (to the CIRF), and 3.7 days outbound transit (from the CIRF).

Ignoring the queueing effects associated with AWM for now (the system performance, including these effects, is evaluated later in this appendix using the optimization model), assume a notional mean CIRF delay time (INW plus AWM) of two days per pod, along with a total CIRF-transit-plus-prep time of five days each way; the mean total pipeline is a 12-day requirement at the FOL. For the ALQ-184–equipped aircraft, the notional A-10 squadron discussed above requires

---

[4] Personal communication, Robbie Ricks, WR-ALC/ITM, via email, February 2004.

[5] Note that no ALQ-184 pods are assigned to USAFE units; the units at Aviano and Spangdahlem ABs use ALQ-131 ECM pods. Thus, ALQ-184 pods were not tested (see HQ USAF, 2002).

$$1.176 * 12 = 14.1 \rightarrow 15$$

pods for its mean pipeline requirement, and this notional F-16 squadron requires

$$1.646 * 12 = 19.8 \rightarrow 20$$

pods for its mean pipeline requirement. For the ALQ-131–equipped aircraft, similar computations produce mean pipeline requirements of eight pods for the notional A-10 squadron and ten pods for the notional F-16 squadron. Thus, the squadron of 24 A-10s needs to deploy 39 ALQ-184 pods to its FOL, and the squadron of 24 F-16s has a requirement of 44 ALQ-184 pods at its FOL. The 24 PAA–squadron of ALQ-131–equipped A-10s needs to deploy 32 pods to its FOL; the 24 PAA–squadron of F-16s has a requirement of 34 ALQ-131 pods at its FOL.

However, additional pods need to be deployed to the OCONUS CIRFs to account for AWP and maintain the two-day CIRF delay time. Four years' worth of pod status data were provided by WR-ALC/ITM.[6] They indicate that on average, at any point in time, 3.3 percent of ALQ-184-Long pods and 7.4 percent of ALQ-131 pods were AWP (worldwide). However, these AWP rates would be expected to increase in a deployment because of the associated increase in daily pod operating hours. Peacetime rates of 5 ILM inductions per ALQ-184 per year (a slight increase over the scheduled workload associated with the pod's 90-day PMI) and 2.5 ILM inductions per ALQ-131 per year (a slight increase over the scheduled workload associated with the pod's 180-day PMI) were computed (see data modeling section of Appendix B). The 39 pods associated with the ALQ-184–equipped A-10 squadron would expect to observe 0.534 ALQ-184 ILM inductions per day when not deployed; the 44 pods associated with the F-16 squadron would expect a peacetime daily mean of 0.603 ALQ-184 ILM inductions. Thus, the deployed A-10 squadron would observe a 2.202 times increase over

---

[6] Data for January 2000 through December 2003 provided by Robbie Ricks, WR-ALC/ITM, February 2004.

the peacetime workload associated with its 39 ALQ-184 pods, and the deployed F-16 squadron would observe an increase of 2.730 times the mean peacetime workload associated with its 44 ALQ-184 pods. Assuming that the AWP rate increases proportionately to the increased workload, this A-10 squadron generates an AWP requirement of

$$2.202 * 0.033 * 39 = 2.8 \rightarrow 3$$

ALQ-184 pods at the CIRF. Using similar logic, the ALQ-184–equipped F-16 squadron generates an AWP requirement of

$$2.730 * 0.033 * 44 = 4.0 \rightarrow 4$$

pods at the CIRF. Adding the FOL and CIRF requirements gives a total ALQ-184 deployment requirement of 42 pods per squadron of 24 A-10s and 48 pods per squadron of 24 F-16s. Considering next the ALQ-131 deployments, the 32 pods associated with this A-10 squadron would expect to observe 0.219 ALQ-131 ILM inductions per day when not deployed, and the 34 pods associated with the F-16 squadron would expect a peacetime daily mean of 0.233 ALQ-131 ILM inductions. Thus, the deployed A-10 squadron would observe an increase of 2.685 times over the peacetime workload associated with its 32 ALQ-131 pods, and the deployed F-16 squadron would observe an increase of 3.532 times the mean peacetime workload associated with its 34 ALQ-131 pods. Again, assuming that the AWP rate increases proportionately to the increased workload, this A-10 squadron generates an AWP requirement of

$$2.685 * 0.074 * 32 = 6.4 \rightarrow 7$$

pods at the CIRF, with the ALQ-131–equipped F-16 squadron generating an AWP requirement of

$$3.532 * 0.074 * 34 = 8.9 \rightarrow 9$$

pods at the CIRF. Adding the FOL and CIRF requirements gives a total ALQ-131 deployment requirement of 39 pods per squadron of 24 A-10s and 43 pods per squadron of 24 F-16s.

In the interest of providing a simple and conservative deployment pod requirement rule, we assumed that two pods would deploy for each deployed ALQ-184–equipped PAA and that two pods would deploy for each deployed ALQ-131–equipped PAA, regardless of MDS. Note that this implies that the full-deployment MRC scenario requires 996 ALQ-184s to support a 498 PAA deployment. This suggests that the entire post-BRAC CONUS inventory of 643 ALQ-184 pods should be retained for deployment requirements, with no pods being retired because of BRAC-related PAA reductions.

Because 49 ALQ-131 pods have already received the MIL-STD-1553 data bus card upgrade, and each AFRC unit has 24 PAA, we assumed that all 49 upgraded pods were assigned to the Homestead AFRC unit to prevent the mixing of ALQ-131 pod modifications at any one site. We assumed that the other five units, containing a total of 102 PAA, were to be assigned two unmodified ALQ-131 pods per PAA, producing a total MRC deployment requirement of 253 ALQ-131s. This suggests that even for a conservative estimate of deployment pod requirements, the entire post-BRAC CONUS inventory of 265 ALQ-131 pods exceeds these units' deployment requirements. BRAC-related PAA reductions may enable a small number of CONUS-assigned ALQ-131 pods to be reassigned to the OCONUS units at Spangdahlem and Aviano ABs that are currently operating the ALQ-131 pod.[7]

ALQ-184 and ALQ-131: Peacetime Pod Requirements Computation

The previous section outlined the computation of deployment pod requirements, which resulted in a total CONUS-wide authorization of 643 ALQ-184 and 253 ALQ-131 pods. It is next necessary

---

[7] Even though this analysis was limited to CONUS pod support, the finding that ALQ-131 requirements on a per-PAA basis are greater than the pre-BRAC allocations (265 pods/237 PAA pre-BRAC versus 253 pods/126 PAA computed requirement) suggests that these OCONUS units likely have a requirement for the 12 additional pods.

to determine the peacetime allocation of these ECM pods to individual units. Note that there are insufficient ALQ-184 pods to satisfy the deployment requirement for all ALQ-184–equipped aircraft; however, there are enough ALQ-131 pods to satisfy each unit's deployment requirement of two pods per ALQ-131–equipped PAA. Thus, each ALQ-131–equipped unit could receive a peacetime pod allocation equal to its deployment pod requirement.

Consider the impact on an ALQ-131–equipped unit that sends its pods to an off-site CIRF for ILM. Recall that scheduled maintenance accounts for the majority of the ECM pod peacetime workload. Each pod must be inspected at its ILM facility at its PMI even if it has not been used since its last scheduled maintenance action. If this ALQ-131–equipped unit has a peacetime pod allocation equal to its deployment requirement of two pods per PAA, a number of pods are likely to return to the unit from its CIRF, receive no use for 180 calendar days, and then be sent back to the CIRF for a PMI. Instead of transporting these unused pods between the unit and its CIRF, a peacetime pod requirement for CIRFed units can be computed in a manner similar to that used for the deployment requirement for ECM pods. Because this peacetime requirement will be less than the deployment requirement, the difference between these requirements could be stored at the CIRF, ready to deploy along with the supported unit. This would eliminate unnecessary transport of pods between the CIRFed unit and its CIRF. Any unit that performs its own ECM pod ILM on site was assumed to keep its entire deployment pod requirement on site.

The goal for this peacetime pod requirement is to ensure that each CIRFed unit maintains at least one FMC pod on hand per PAA. Implementing commonly used USAF pipeline computations, we set the peacetime pod requirement for CIRFed units equal to the unit's PAA, plus the mean pipeline between the unit and its CIRF, plus one standard deviation of this pipeline, assuming an exceedingly conservative 14-calendar day total base pipeline time. To compute this requirement for CIRFed units, set *a* equal to the pipeline time multiplied by the pod induction rate (for the ALQ-131, this is equal to 14*1/146), and set b equal to the number of PAA at the unit. Then the unit's peacetime pod requirement is the smallest integer x such that

$$ax + \sqrt{ax} \leq x - b.$$

Solving this inequality produces CIRFed unit pod requirements of 22 ALQ-131s at 18 PAA units and 29 ALQ-131s at 24 PAA units.[8] As an illustration of how these pod allocations would work in practice, suppose that Atlantic City ANG (18 PAA) and Davis-Monthan AFB (24 PAA) received ALQ-131 ILM at a CIRF at Burlington ANG (18 PAA). The peacetime allocation of pods would then be 22 at Atlantic City ANG, 29 at Davis-Monthan AFB, and 69 at Burlington ANG, with Burlington receiving its deployment requirement of 36 pods plus an additional 14 pods from Atlantic City ANG and an additional 19 pods from Davis-Monthan AFB.

If this computation is applied to the ALQ-184 pods, the total CIRFed unit pod requirement, summed over all units, exceeds the total pool of 643 ALQ-184 pods. Instead, these 643 pods received a peacetime allocation that was proportional to each unit's PAA. Note, however, that this computation does not necessarily imply that the ALQ-184 pod cannot be supported using CIRFs, because the 14-day CIRF pipeline time assumed here is very conservative. In upcoming sections, the optimization model will use actual transport, repair, and queueing times to determine the performance of CIRF networks for the ALQ-184 and ALQ-131 pods.

ALQ-184 and ALQ-131: Deployment Scenario Data and Inputs

The CONUS ALQ-184 units presented in Table D.1 account for 150 A-10/OA-10 PAA and 348 F-16 PAA. The CONUS ALQ-131 units presented in Table D.1 account for 24 A-10/OA-10 PAA and 102 F-16 PAA. The 20 percent deployment scenario presented in Appendix B accounts for a deployment of 30 ALQ-184–equipped A-10 PAA, 70 ALQ-184–equipped F-16 PAA, five ALQ-131–equipped

---

[8] This value was determined by solving the following quadratic equation (using the larger of the roots): $(1-2a+a^2)x^2-(2b(1-a)+a)x+b^2 = 0$.

A-10 PAA, and 22 ALQ-131–-equipped F-16 PAA. Under this scenario, the 30 ALQ-184–equipped A-10s deployed to two different FOLs, each with 15 aircraft; the ALQ-184–equipped F-16s deployed to three different FOLs, with 24, 24, and 22 PAA, respectively; and the ALQ-131–equipped A-10s and ALQ-131–equipped F-16s each deployed to a different FOL. It was assumed that all deployed ALQ-184 pods were supported using a single OCONUS CIRF, with another OCONUS CIRF used to support all deployed ALQ-131 pods. Note that five of the ALQ-131–equipped F-16s were assumed to be sourced from the unit at Homestead AFRC that possesses pods that have been upgraded with the MIL-STD-1553 data bus card.

It is important to note that the previous two sections' analyses were used solely to determine pod deployment requirements and peacetime pod allocations. As with the JEIM analyses, the optimization model presented in Appendix A was used to determine the efficient frontier cost-performance curves and to identify an alternative ALQ-184 CIRF network and an alternative ALQ-131 network.

The ALQ-184 deployment scenario of 30 A-10/OA-10s and 70 F-16s has a total pod requirement of 200 deployed ALQ-184s. The ALQ-131 deployment scenario of five A-10/OA-10s and 22 F-16s has a total pod requirement of 54 deployed ALQ-131s. The ALQ-184 peacetime pod allocation and its pod allocation for the deployment scenario are presented in Table D.2. Table D.3 contains the peacetime and deployment scenario ALQ-131 pod allocations for each unit in each instance—i.e., if the unit performs its pod ILM on site and if the unit receives ILM at an off-site CIRF.

The transit times between bases were obtained using the DoD Standard Transit Time—Truckload (U.S. DoD, 2006). One additional day was added to each transit leg to allow for transit preparation time. The transport costs were obtained from the CIRF CONOPS Transportation Computation Chart (HQ USAF, 2004) assuming an air-ride truck with expedited service, dual drivers, CSS, and exclusive use for each shipment. These transportation cost data provide a scale of per-mile transport costs that depend on distance traveled. Because of uncertainties that arose during this study about ECM pod transport costs, this analysis assumed that all ALQ-184 and ALQ-131 shipments

Table D.2
ALQ-184 Pod Allocation by Base: Peacetime and Deployment Scenario

Base Name	Peacetime	Deployment Scenario
Hill AFB (Utah)	93	64
Moody AFB (Georgia)	62	43
Shaw AFB (South Carolina)	93	64
Andrews ANG (Maryland)	23	16
Boise ANG (Idaho)	23	16
Dannelly ANG (Alabama)	23	16
Des Moines ANG (Iowa)	23	16
Duluth ANG (Minnesota)	21	14
Ft. Smith ANG (Arkansas)	23	16
Ft. Wayne ANG (Indiana)	23	16
Joe Foss ANG (South Dakota)	23	16
Kirtland ANG (New Mexico)	23	16
Martin State ANG (Maryland)	23	16
McEntire ANG (South Carolina)	31	21
Selfridge ANG (Michigan)	31	21
Toledo ANG (Ohio)	23	16
Truax ANG (Wisconsin)	23	16
Tulsa ANG (Oklahoma)	28	19
Whiteman AFRC (Missouri)	31	21

would incur the maximum per-mile transport cost presented in the CIRF CONOPS Transportation Computation Chart: $3.08 per mile. It was assumed that no pod pipeline or transit cost was encountered for those pods receiving ILM at their home-station bases. A five-day, one-way transit time from any FOL to the OCONUS CIRF was

Table D.3
ALQ-131 Pod Allocation by Base: Peacetime and Deployment Scenario

	Performs Home-Station ILM		Receives ILM at Off-Site CIRF	
Base Name	**Peacetime**	**Deployment Scenario**	**Peacetime**	**Deployment Scenario**
Davis-Monthan AFB	48	38	29	23
Atlantic City ANG (New Jersey)	36	28	22	18
Buckley ANG (Colorado)	36	28	22	18
Burlington ANG (Vermont)	36	28	22	18
Homestead AFRC	49	39	29	23
Fort Worth–Carswell AFRC	48	38	29	23

assumed in keeping with the USAFE CIRF test discussed previously. Note that OCONUS transit cost was not considered in this study.[9]

The operating cost used in this analysis of ECM pod ILM was defined as the associated personnel cost using a factor of $60,000 per man-year. No CIRF setup cost was considered in this analysis.

Recall that the ALQ-184 failure rate was computed to be 0.0196 per ALQ-184 operating hour and that during peacetime operations, ALQ-184 pods experience a mean of five ILM inductions per year. Similarly, recall that the ALQ-131 failure rate was computed to be 0.0098 per ALQ-131 operating hour and that during peacetime operations, ALQ-131 pods experience a mean of 2.5 ILM inductions per year. Recall also the mean pod repair times of 27.2 hours per ALQ-184 ILM induction and 33.2 hours per ALQ-131 ILM induction. CONUS pod ILM shops were assumed to operate 16 hours per day, five days per week, requiring two eight-hour shifts per line and a 40-hour workweek

[9] OCONUS transport costs were not included because they are not affected by the CONUS CIRF network design. However, estimates of potential OCONUS-CONUS transport costs are presented later in this appendix (see ALQ-184 and ALQ-131: Other Considerations, pp. 229–235).

per man. The OCONUS CIRF was assumed to operate 24 hours per day, seven days per week, with two daily shifts of 12 hours each and a 60-hour workweek per man. Relatively small economies of scale were identified for EW pod ILM from the LCOM simulation analysis discussed in Appendix A. As with the engine analyses, maintenance manpower was adjusted using Man-Hour Availability Factors, with additional management and support positions added to the requirement. No differentiation was made between "types" of full-time manpower (e.g., active duty versus ANG). It was assumed that OCONUS FOLs sent all ECM pod failures to the ALQ-184 or ALQ-131 OCONUS CIRF, as appropriate. The ALQ-184 OCONUS CIRF was assumed to be staffed entirely by personnel deploying from the ALQ-184 CONUS CIRFs; similarly, the ALQ-131 OCONUS CIRF was assumed to be staffed entirely by personnel deploying from the ALQ-131 CONUS CIRFs.

The pre-BRAC manning at these units was obtained from UMDs and determined to be 228 full-time positions for the ALQ-184, with 255 drill positions in the ANG and AFRC.[10] Note that 132 of these drill personnel are also counted within the 228 full-time positions, so 351 total ALQ-184 ILM manpower personnel were available in CONUS to support contingency operations. ALQ-131 manning was determined to be 113 full-time positions, with 94 drill positions in the ANG and AFRC. Note that 54 of these drill personnel are also counted within the 113 full-time positions, so 153 total ALQ-131 ILM manpower personnel were available in CONUS to support contingency operations. Note that some of these positions for each pod type reflect management and support personnel whose responsibilities cover the larger area of avionics maintenance and are not entirely attributable to ECM pod maintenance. Annual manning costs were again assumed to be $60,000 per full-time position and $15,000 per drill position, giving a pre-BRAC ALQ-184 annual manning cost of $17.5 million and a pre-BRAC ALQ-131 annual manning cost of $8.2 million.

---

[10] Massey, 2004.

An AN/ALM-233D electronic test stand is required to perform ALQ-184 ILM. An AN/ALM-256 electronic test stand is required to perform ALQ-131 ILM. Pre-BRAC, 36 AN/ALM-233D and 20 AN/ALM-256 test stands were assigned to CONUS units. It was assumed that no additional test stands of either type could be procured; it was further assumed that although Eielson AFB reassigned one-half of its ALQ-184 pods to CONUS units, it would retain both of its pre-BRAC test stands.

These test stands are themselves subject to periodic failures. Data obtained from WR-ALC indicated widely varying FMC rates for test stands across different bases.[11] One explanation offered for these variations was the difference between units with multiple test stands and units with one test stand. Units with multiple test stands frequently cannibalize parts from one test stand to keep another FMC. Because these test stands are used rather infrequently during peacetime (on average, 5.0 annual ILM inductions per ALQ-184, and 2.5 annual ILM inductions per ALQ-131), units with multiple test stands can afford to leave a cannibalized test stand less than FMC for long periods. This situation does not apply to the CIRF concept, since a CIRF would be sized to support its designated workload and would not typically have many idle test stands. Thus, we considered only units with single test stands as a source for test stand availability data, since these units have a need to keep their single test stand FMC to the greatest extent possible. For the 27 ALQ-184 units identified as having single test stands (all of which were in the ANG or AFRC), the AN/ALM-233D had a mean FMC rate of 88.0 percent. For the seven ALQ-131 single-test-stand units identified (all of which were also in the ANG or AFRC), the AN/ALM-256 had a mean FMC rate of 92.9 percent. These FMC rates were assumed to apply to all test stands in the analysis. It was further assumed that partially mission-capable test stands could not be used for pod ILM—a test stand that was less than FMC could not be used to perform any pod ILM.

---

[11] Data for July 2003 through February 2004 provided by Malcolm Baker, WR-ALC/ITM, May 4, 2004.

The metric used to evaluate the performance of the ECM pod CIRF network is not the serviceable spare count used in the engine analyses. The objective for ECM pods is to ensure that every deployed sortie has an FMC ECM pod, so the metric used in this analysis is the ratio of FMC pods to assigned aircraft. This ratio is presented for both the CONUS and the deployed OCONUS fleet.

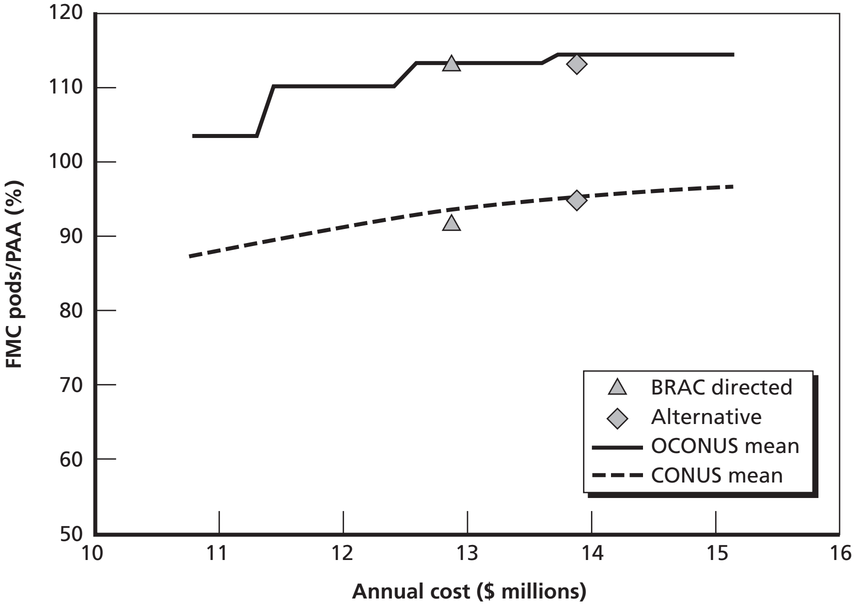
Recall that a worldwide average of 3.3 percent AWP was determined for ALQ-184 pods, and an average of 7.4 percent AWP for ALQ-131 pods. Because of the deployed flying schedule's higher operating tempo, the deployed pod AWP fraction was increased for each pod type in proportion to the deployment scenario's increased pod failure rate when compared against its peacetime ECM pod ILM induction rate. The AWP rates of 3.3 percent for ALQ-184 and 7.4 percent for ALQ-131 were unchanged for the CONUS pod remainders. Applying this increased AWP rate to the deployment size of 200 ALQ-184 pods gives a mean expectation of 15.1 AWP pods, with another 14.6 pods AWP at the CONUS units. Applying this increased AWP value to the deployment size of 54 ALQ-131 pods gives a mean expectation of 9.5 AWP pods, with another 14.7 pods AWP at the CONUS units.

It was assumed that the pod ILM structure would have no effect on repair times. Given the assumed repair rates and accounting for the differences in CONUS and OCONUS work schedules and flying schedules, a mean of 7.1 ALQ-184 pods is expected INW at the OCONUS CIRF, with an overall mean of 14.4 ALQ-184 pods across all CONUS units independent of the CONUS ILM network. Similarly, a mean of 1.2 ALQ-131 pods is expected INW at the OCONUS CIRF, with an overall mean of 4.0 ALQ-131 pods across all CONUS units independent of the CONUS ILM network. Note that the OCONUS INT pipeline, containing a mean of 62.6 ALQ-184 and 8.8 ALQ-131 pods, is also independent of the CONUS ILM structure. These considerations yield a maximum possible mean FMC value of 115 ALQ-184 pods OCONUS, 414 ALQ-184 pods CONUS, 35 ALQ-131 pods OCONUS, and 180 ALQ-131 pods CONUS (assuming zero pods AWM and zero pods in the CONUS transit pipeline). Because the deployment scenario accounts for 100 total ALQ-184–equipped PAA deployed OCONUS and 398 total ALQ-184–equipped PAA remaining in CONUS, the maximum possible mean ratio of FMC ALQ-184 pods to PAA is 115 percent OCONUS and 104 percent CONUS. Similarly, because the deployment scenario accounts for 27 total ALQ-131–equipped PAA deployed OCONUS and 99 total ALQ-131–equipped PAA remaining in CONUS, the maximum possible mean ratio of FMC ALQ-131 pods to PAA is 130 percent OCONUS and 182 percent CONUS.

ALQ-184: Deployment Scenario

Figure D.3 presents the results of the deployment scenario analysis for the ALQ-184 ILM structure, demonstrating the tradeoff between annual cost (transport cost plus operating cost) and the achieved ratio of FMC pods to PAA for both the CONUS and the OCONUS fleets. The optimization model presented in Appendix A was used to identify the points defining these curves, which demonstrate the best system performance available for any level of expenditures. Note that "best system performance" in this case refers to the maximum total number of FMC pods systemwide (both CONUS and OCONUS). Note that these efficient frontier curves actually represent a very large number of potential solutions: for any level of expenditures along these curves (e.g., 110 percent FMC/PAA OCONUS and 92 percent FMC/PAA CONUS at a total cost of $12 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the ALQ-184–equipped combat-coded CONUS PAA, the mean ALQ-184 FMC level can be kept above 100 percent of OCONUS PAA, although the CONUS remainder cannot be supported at a mean FMC level of 100 percent with respect to PAA. The poor performance of the CONUS remainder occurs because a very large number of spare pods were deployed OCONUS. The reason that CONUS performance cannot reach its upper bound of 104 percent FMC is the limited number of test stands. If no limit were placed on the maximum number of maintenance lines (as in the engine analyses), CONUS performance would approach its maximum of 414 FMC pods. However, the constraint of having only 36 total test stands available means that a significant number of pods remain in AWM status, thus preventing this maximum performance level from being achieved.

Figure D.3
ALQ-184 CIRF Network Options: Deployment Scenario



RAND *MG418-D.3*

Recall that all deployed ECM pods receive ILM at an OCONUS CIRF. Because a five-day transport time was assumed between all FOLs and the OCONUS CIRF, OCONUS performance is strictly a function of the number of test stands placed at the OCONUS CIRF, leading to a performance curve that resembles a step function.

Data obtained from WR-ALC indicate that over the four-year period of 2000 through 2003, 86.2 percent, on average, of ALQ-184 pods were FMC (worldwide).[12] This metric is somewhat difficult to compare with the results presented in Figure D.3. Note that this number presents the fraction of total pods that were FMC but provides no information on pod availability with respect to the associated number of aircraft. Applying this rate to the total CONUS pool of 643 ALQ-184 pods implies that a mean of 554 FMC pods could be

---

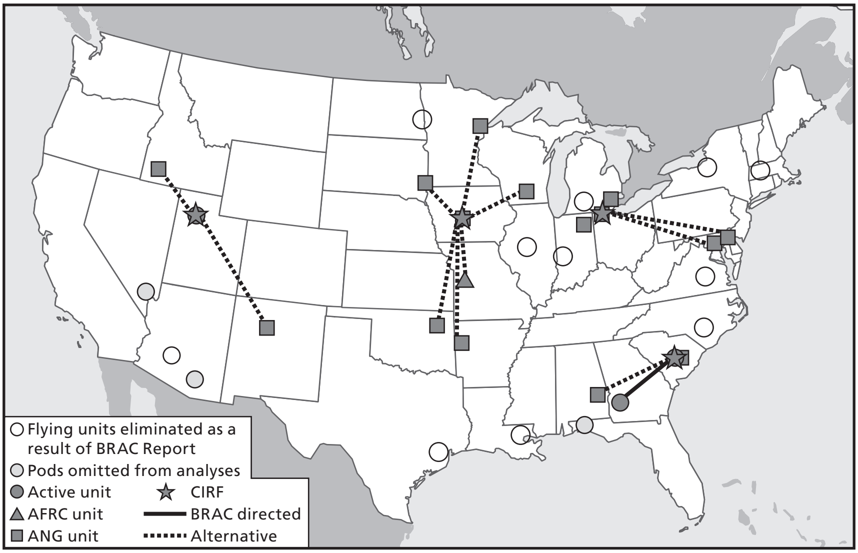
[12] Data for January 2000 through December 2003 provided by Robbie Ricks, WR-ALC/ITM, February 2004.

expected from the current CONUS ALQ-184 ILM network. However, these data do not reflect the post-BRAC force structure. Moreover, the worldwide pod availability data do not reflect the same deployment flying schedule (this four-year period includes support of OEF and OIF), making direct comparison with these results somewhat difficult. Most significantly, this single worldwide FMC rate does not differentiate between the availability of deployed pods and the availability of CONUS pods.

To provide a fairer basis for comparison, we evaluated the post-BRAC ALQ-184 network presented in Figure D.1 using the optimization model. We found that it could achieve a mean of 113 percent FMC/PAA OCONUS and 92 percent FMC/PAA CONUS at a total cost of $12.9 million. Although the post-BRAC ALQ-184 network is rather cost-effective (i.e., it lies very near both efficient frontier curves), other solutions lying on the efficient frontier curves could be selected according to the decisionmaker's preference. For example, for a performance goal of 95 percent FMC/PAA CONUS, one can identify a solution on the efficient frontier curves of Figure D.3 that meets this standard at a minimum total cost of $13.9 million. The network configuration associated with this alternative solution is presented in Figure D.4. It is important to note that the curves appearing in Figure D.3 are rather flat in the vicinity of the alternative solution, which suggests that alternative CONUS CIRF network designs can be identified that differ only slightly in performance but may be preferable for considerations outside the scope of this analysis.

Note that both solutions maintain an OCONUS FMC pod level that exceeds the PAA requirement. Recall that the computation of the deployment pod requirement assumed a two-day delay time at the CIRF to account for INW and AWM times. The mean repair time for an ALQ-184 pod is 27.2 hours; since the OCONUS CIRF operates 24 hours per day, seven days per week, the mean INW time per ILM induction will take slightly more than one day. Because this optimization analysis computes the actual mean AWM time based on the number of test stands at the OCONUS CIRF, as more test stands are

Figure D.4
ALQ-184: Alternative CIRF Network



RAND *MG418-D.4*

added to the OCONUS CIRF, the mean AWM time can decrease to a level such that the total CIRF delay time is less than two days. In this case, the deployment pod allocation would provide for slightly more pods than are needed. Also, recall that the deployment pod requirement levels were increased slightly from the computed values of 42 and 48 ALQ-184 pods per 24 PAA squadron of A-10s and F-16s, respectively, to a requirement of two pods per deployed PAA, allowing for a simple and conservative rule. These factors work together to allow the mean OCONUS FMC pod/PAA value to exceed 100 percent.

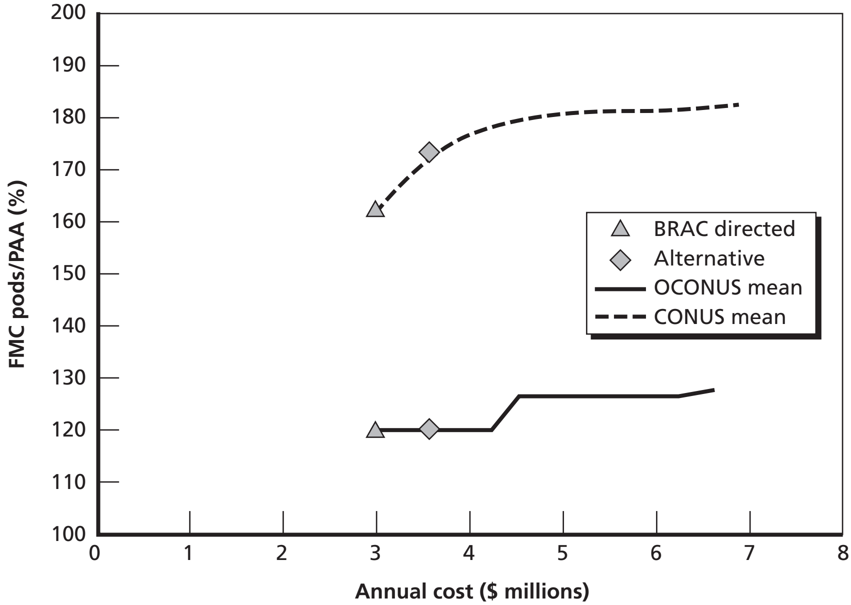
Note, however, that what Figure D.3 presents is the average performance over time. At any point in time, the system's actual performance would be expected to vary around this mean. Because it is necessary to have an FMC pod for each deployed sortie, this mean value should be greater than 100 percent. For both the alternative CIRF network and the post-BRAC network, the OCONUS ratio of FMC ALQ-184 pods to PAA lies between 108 percent and 120 percent one-half of the time (exceeding this interval one-quarter of the time, and lying below this interval one-quarter of the time).

The alternative CIRF network has a total full-time manpower requirement of 183, with a total manning of 117 at the CONUS CIRFs, and 66 manpower positions at the OCONUS CIRF. The post-BRAC network has a total full-time manpower requirement of 207, with a total manning of 141 at the CONUS ILM facilities, and 66 manpower positions at the OCONUS CIRF. The alternative solution requires a total of 21 test stands at CONUS CIRFs and ten test stands at the OCONUS CIRF; the post-BRAC network requires a total of 24 test stands at CONUS ILM facilities and ten test stands at the OCONUS CIRF. Notice that the alternative solution requires 24 fewer full-time maintenance positions but requires greater expenditures for CONUS transportation, with a transport cost of $2.9 million for the alternative solution and $0.4 million for the BRAC-directed network.

ALQ-131: Deployment Scenario

Figure D.5 presents the results of the deployment scenario analysis for the ALQ-131 ILM structure, demonstrating the tradeoff between annual cost (transport cost plus operating cost) and the achieved ratio of FMC pods to PAA for both the CONUS and the OCONUS fleets. The optimization model presented in Appendix A was used to identify the points defining these curves, which demonstrate the best system performance available for any level of expenditures. Note that "best system performance" in this case refers to the maximum total number of FMC pods systemwide (both CONUS and OCONUS). Note that these efficient frontier curves actually represent a very large number of potential solutions: for any level of expenditures along these curves (e.g., 127 percent FMC/PAA OCONUS and 180 percent FMC/PAA CONUS at a total cost of $5 million), an associated CIRF network design has been identified. Observe that even for an indefinite deployment of 20 percent of the ALQ-131–equipped combat-coded CONUS PAA, the ALQ-131 FMC level can be kept above 100 percent with respect to both OCONUS and CONUS PAA. The good performance here occurs

Figure D.5
ALQ-131 CIRF Network Options: Deployment Scenario



RAND *MG418-D.5*

because such a large number of spare pods are available. Note that even with a limit placed on the total number of available test stands, CONUS performance and OCONUS performance approach their upper bounds of, respectively, 182 percent and 130 percent, indicating that the total of 20 test stands is sufficient to maintain a very small number of pods in AWM status. Recall that all deployed pods receive ILM at an OCONUS CIRF. Because a five-day transport time was assumed between all FOLs and the OCONUS CIRF, OCONUS performance is strictly a function of the number of test stands placed at the OCONUS CIRF, leading to a performance curve that resembles a step function.

Data obtained from WR-ALC indicate that over the four-year period of 2000 through 2003, 83.3 percent, on average, of ALQ-131 pods were FMC (worldwide).[13] This metric is somewhat diffi-

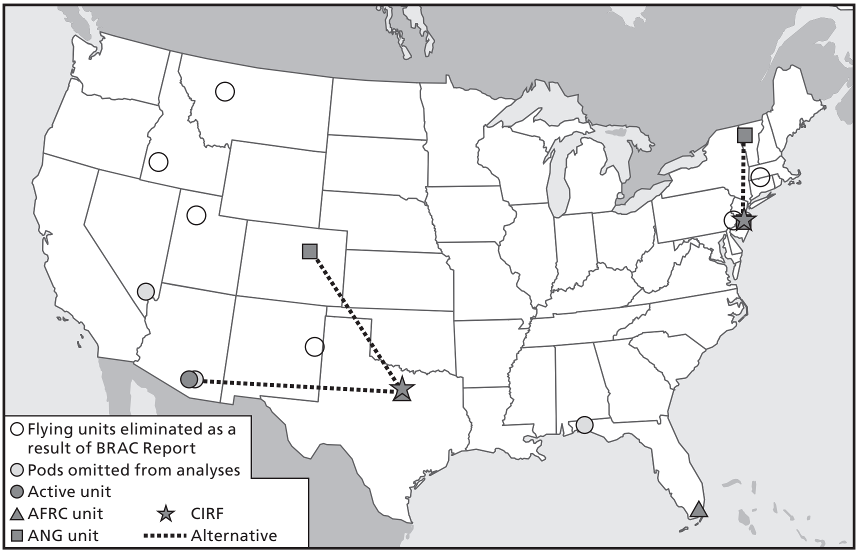
---

[13] Data for January 2000 through December 2003 provided by Robbie Ricks, WR-ALC/ITM, 2004.

cult to compare with the results presented in Figure D.5. Note that this number represents the fraction of total pods FMC and provides no information about pod availability with respect to the associated number of aircraft. Applying this rate to the total pool of 253 ALQ-131 pods implies that a mean of 211 FMC pods could be expected from the current CONUS ALQ-131 ILM network. However, these data do not reflect the post-BRAC force structure. Moreover, the worldwide pod availability data do not reflect the same deployment flying schedule (this four-year period includes support of OEF and OIF), making direct comparison with these results somewhat difficult. Most significantly, this single worldwide FMC rate does not differentiate between the availability of deployed pods and the availability of CONUS pods. To provide a fairer basis for comparison, we evaluated the post-BRAC ALQ-131 network presented in Figure D.2 using the optimization model. It achieved a mean of 120 percent FMC/PAA OCONUS and 163 percent FMC/PAA CONUS at a total cost of $3.0 million. Although the post-BRAC ALQ-131 network is cost-effective (i.e., it lies on both efficient frontier curves), other solutions lying on the efficient frontier curves could be selected according to the decisionmaker's preference. For example, for a performance goal of 175 percent FMC/PAA CONUS, one can identify a solution on the efficient frontier curves of Figure D.5 that meets this standard at a minimum total cost of $3.6 million. The network configuration associated with this alternative solution is presented in Figure D.6. It is important to note that the curves appearing in Figure D.5 are rather flat in the vicinity of the alternative solution, which suggests that alternative CONUS CIRF network designs can be identified that differ only slightly in performance but may be preferable for considerations outside the scope of this analysis.

As with the ALQ-184 analysis, both ALQ-131 solutions maintain an OCONUS FMC pod level that exceeds the PAA requirement. This high level of OCONUS ALQ-131 performance occurs because of the same factors that influenced ALQ-184 performance. With a sufficient number of OCONUS test stands, the optimization procedure is able to produce a total CIRF delay time (INW plus AWM) that is less than the two-day delay assumed in the computation of the deployment

Figure D.6
ALQ-131: Alternative CIRF Network



RAND *MG418-D.6*

pod requirement. Also, recall that the deployment pod requirement levels were increased slightly from the computed values of 39 and 43 ALQ-131s per 24 PAA squadron of A-10s and F-16s, respectively, to a requirement of two pods per deployed PAA, allowing for a simple and conservative rule. These factors work together to allow the mean OCONUS FMC pod/PAA ratio to exceed 100 percent.

Recall that what Figure D.5 presents is average performance over time. At any point in time, the system's actual performance would be expected to vary around this mean. Because it is necessary to have an FMC pod for each deployed sortie, this mean value should be greater than 100 percent. For both the alternative CIRF network and the post-BRAC network, the OCONUS ratio of FMC ALQ-131 pods to PAA lies between 109 percent and 143 percent one-half of the time (exceeding this interval one-quarter of the time, and lying below this interval one-quarter of the time).

The alternative CIRF network has a total full-time manpower requirement of 48, with a total manning of 34 at the CONUS CIRFs, and 14 manpower positions at the OCONUS CIRF. The post-BRAC network has a total full-time manpower requirement of 50, with a total manning of 36 at the CONUS ILM facilities, and 14 manpower positions at the OCONUS CIRF. Both the alternative solution and the post-BRAC network require a total of six test stands at CONUS ILM facilities and two test stands at the OCONUS CIRF. Notice that the alternative solution requires two fewer full-time maintenance positions but requires greater expenditures for CONUS transportation, with a transport cost of $0.7 million for the alternative solution and no transport cost for the BRAC-directed network.

ALQ-184 and ALQ-131: Other Considerations

The manpower requirements associated with the alternative solutions place a heavy deployment burden on ALQ-184 and ALQ-131 maintenance personnel. If the alternative network's total CONUS ALQ-184 manning of 117 personnel is used to support its OCONUS manpower requirement of 66 positions, all full-time ALQ-184 ILM personnel would be required to spend more than one-third of their time deployed OCONUS. If the alternative network's total CONUS manning of 34 ALQ-131 personnel is used to support its OCONUS manpower requirement of 14 positions, all full-time ALQ-131 ILM personnel would be required to spend slightly less than one-third of their time deployed OCONUS. Unfortunately, the alternative policies that were used to mitigate the deployment burden on engine maintenance personnel are less applicable to ECM pod maintenance. For F110 and F100 engines, a subset of retained tasks that would be performed at the OCONUS CIRF was identified in an attempt to balance the opposing demands of limiting deployed personnel and limiting OCONUS-CONUS transport. The retained task concept does not apply to ECM pods, however, since the extent of a pod failure cannot be determined without first testing the pod using the test stand. Once the pod failure has been identified on the test stand, pod maintenance is a relatively easy task provided the necessary parts are on hand. Thus, the retained task option is precluded. The alternative policy used to limit deployment burden on TF34 engines was to perform all TF34 JEIM, for both CONUS and OCONUS aircraft, at CONUS CIRFs. While such a policy eliminates the deployment burden on maintenance personnel, it imposes a burden on strategic lift between OCONUS and CONUS. For the TF34 engine, the deployment scenario has an annual requirement of 82 engine shipments (each way) between the FOLs and CONUS CIRFs. Because of the higher frequency of ECM pod failures, a policy of performing all repair in CONUS would require 2,285 ALQ-184 and 322 ALQ-131 pod shipments (each way) annually between the FOLs and CONUS CIRFs. While it is true that multiple failed pods could to some extent be batched together and transported in the same shipment, this still places an extremely heavy burden on the strategic lift assets. Another disadvantage of this policy is that additional pods would be needed at the OCONUS FOLs to account for the longer pipelines associated with the longer OCONUS-CONUS transport leg. This would further reduce the availability of pods at CONUS units, which would be especially problematic for the ALQ-184. Also, recall that OCONUS transit cost was not modeled in this study. The cost to transport an ECM pod at the AMC channel rate between Dover AFB and Al Udeid (for example) is $1,693 each way per ALQ-184, and $1,797 each way per ALQ-131.[14] The annual transit cost to ship all 2,285 ALQ-184 pod shipments round-trip would thus be $7.7 million, with an annual transit cost of $1.2 million to ship all 322 ALQ-131 pods round-trip. These OCONUS transit costs would be rather expensive relative to their associated manpower costs. Note, however, that the cost of transportation between the OCONUS FOL and OCONUS CIRF was not included in this analysis.

Suppose that these transport limitations preclude the policy of all repair in CONUS. Assume a goal consistent with the general AEF construct, wherein full-time USAF personnel are eligible to spend one-fifth of their time deployed, which implies that five full-time manpower positions are required systemwide to support one position perpetually deployed. If all positions are to be filled by full-time personnel, the 66 full-time ALQ-184 positions at the OCONUS CIRF would require

---

[14] ALQ-184-Long weight is 635 lb (Raytheon, 2005); ALQ-131 (three-band-deep configuration) weight is 674 lb (Northrop Grumman, undated); AMC channel rate between Dover AFB and Al Udeid is $2.666 per lb each way (U.S. Government, 2005).

330 full-time manpower positions systemwide, and the 14 full-time ALQ-131 positions at the OCONUS CIRF would require 70 full-time manpower positions systemwide. This is an increase of 147 ALQ-184 positions and 22 ALQ-131 positions beyond their alternative solutions' full-time manning of 183 and 48, respectively. At any point in time, 264 of these full-time ALQ-184 positions and 56 of these full-time ALQ-131 positions would be in CONUS, which is much larger than the 117 and 34 respective manpower positions required for the residual CONUS fleets' workload. This amounts to increases of 126 percent and 65 percent over the required full-time CONUS manning for the ALQ-184 and ALQ-131, respectively, implying that the CONUS workforce would be highly underutilized.

An alternative policy for ECM pod ILM that would decrease the deployment burden on full-time personnel is to use activated part-time personnel to fill some fraction of the full-time manpower positions required to support this 20 percent deployment scenario. Recall that the alternative solution has a CONUS full-time manning of 117 for the ALQ-184 and 34 for the ALQ-131. This number of CONUS positions could be used to support 29 permanently deployed ALQ-184 positions and eight permanently deployed ALQ-131 positions with a deployment burden that does not exceed one-fifth. This leaves an additional 37 full-time ALQ-184 positions and six full-time ALQ-131 positions at the OCONUS CIRFs. Suppose that these 37 ALQ-184 positions and six ALQ-131 positions were to be filled by activated part-time personnel. The current AEF cycle calls for forces to meet a 120-day eligibility window over a 20-month cycle. Assume that reserve component personnel could be activated once every two AEF cycles, which implies that these personnel could expect to be activated one-tenth of the time over a 40-month period. If these OCONUS CIRF positions were to be filled by activated part-time personnel, observing such guidelines would require 370 total part-time ALQ-184 personnel and 60 part-time ALQ-131 personnel. For the ALQ-184, contrast the cost of staffing 370 part-time positions ($5.6 million) with the policy of filling an additional 147 full-time positions ($8.8 million). Similarly for the ALQ-131, the comparison should be made between the cost of staffing

60 part-time positions ($0.9 million) and the alternative policy of filling an additional 22 full-time positions ($1.3 million).

Note that these computations are very different from the part-time personnel computations for the engine analyses. For those analyses, the part-time manning requirement was determined from the MRC scenario, and part-time personnel were not necessary to support the 20 percent deployment scenario. The 370 part-time ALQ-184 personnel and 60 part-time ALQ-131 personnel associated with this ECM pod analysis are needed to support the 20 percent deployment scenario; computation of the part-time ECM pod personnel necessary for the MRC scenario requires a different analysis.

If ILM manpower is designed to support sustained deployment operations assuming shop operations of 24 hours per day, seven days per week and a 60-hour workweek (as in the OCONUS CIRF policy), little additional capacity is available to support more-stressing, surged operations. Under the assumed CONUS CIRF policy, manpower and test stands operating at CONUS CIRFs could support a heavier workload during surged operations through utilization of a 60-hour workweek environment. However, the total number of test stands available is likely to be the limiting factor in such a large deployment.

Consider the MRC scenario presented in Appendix B in the interest of determining the part-time manning requirement in the reserve component. Recall that all ALQ-184– and ALQ-131–equipped squadrons in this analysis are combat coded, so there is no need to retain any test stands at CONUS units. Because there are 36 AN/ALM-233D test stands and 20 AN/ALM-256 test stands available, suppose that the OCONUS CIRF in each theater operates 18 AN/ALM-233Ds and 10 AN/ALM-256s. This would require a total manning of 119 positions at each ALQ-184 CIRF and 66 positions at each ALQ-131 CIRF, for a total MRC manning of 238 ALQ-184 positions and 132 ALQ-131 positions. This MRC manning for the ALQ-184 is smaller than the total manning required to support the 20 percent deployment scenario if either policy is used to maintain a deployment burden of no greater than one-fifth. However, for the ALQ-131, this MRC manning is greater than the total manning required to support the 20 percent deployment scenario for both policies used to maintain a deployment burden of no greater than one-fifth. This difference between the two pod types is attributable to the relative scarcity of AN/ALM-233D test stands compared with the number of AN/ALM-256 test stands in light of each one's workload requirement. There are over 2.5 times as many ALQ-184 pods as ALQ-131 pods in this analysis, and the ALQ-184 pod's failure rate is twice that of the ALQ-131; yet there are only 1.8 times as many AN/ALM-233D test stands as AN/ALM-256 test stands.

The efficient frontier curves presented in Figures D.3 and D.5 represent a very large number of potential solutions. Each point lying on these curves is associated with a specific CIRF network design. Table D.4 summarizes the maintenance and transportation costs and the system performance and manpower requirements associated with the 20 percent deployment scenario for the post-BRAC and alternative CIRF networks for the ALQ-184 pod. Table D.5 presents similar information for the ALQ-131 pod.

As Tables D.4 and D.5 indicate, some of the OCONUS full-time personnel are also counted in the CONUS part-time manning when activated part-time personnel are used to manage the deployment burden. Under such a policy, activated part-time personnel incur both their part-time manning cost as well as the associated full-time manning cost, since these activated positions are perpetually filled by alternating personnel.

Because of the limitations imposed by the deployment burden, the gains associated with centralization of ALQ-184 maintenance are less than those for TF34, F110, and F100 JEIM. The ALQ-131 network's small scale causes the benefits associated with centralization of ALQ-131 maintenance to be less than those achieved for the JEIM analyses. And the uncertainties associated with deployed pod failure rates lessen the strength of the ECM CIRF recommendations. However, these results still indicate that a small number of ALQ-184 CIRFs and ALQ-131 CIRFs can simultaneously provide a cost-effective solution and acceptable performance.

Table D.4
Cost and Performance: ALQ-184 CIRF Networks

	BRAC Directed		Alternative	
Maintenance locations (CONUS/OCONUS)	18/1		4/1	
FMC pods/PAA (%)				
CONUS	92		95	
OCONUS	113		113	
Transportation ($M)	0.4		2.9	
Mean transport pipeline				
CONUS pods	3.3		25.1	
OCONUS pods	62.6		62.6	
Means for managing deployment burden	Additional full-time personnel	Activated part-time personnel	Additional full-time personnel	Activated part-time personnel
Payroll ($M)	19.8	17.1	19.8	16.5
Total ($M)	20.2	17.5	22.7	19.4
Manning				
CONUS full-time	264	141	264	117
CONUS part-time	0	310	0	370
OCONUS full-time	66	66[a]	66	66[a]

[a] Some of these personnel are also counted in CONUS part-time manning when activated part-time personnel are used to manage the deployment burden.

Table D.5
Cost and Performance: ALQ-131 CIRF Networks

	BRAC Directed		Alternative	
Maintenance locations (CONUS/OCONUS)	6/1		3/1	
FMC pods/PAA (%)				
CONUS	163		173	
OCONUS	120		120	
Transportation ($M)	0.0		0.7	
Mean transport pipeline				
CONUS pods	0.0		3.5	
OCONUS pods	8.8		8.8	
Means for managing deployment burden	Additional full-time personnel	Activated part-time personnel	Additional full-time personnel	Activated part-time personnel
Payroll ($M)	5.1	4.2	5.1	4.1
Total ($M)	5.1	4.2	5.8	4.8
Manning				
CONUS full-time	56	36	56	34
CONUS part-time	62	82	62	84
OCONUS full-time	14	14[a]	14	14[a]

[a] Some of these personnel are also counted in CONUS part-time manning when activated part-time personnel are used to manage the deployment burden.

Bibliography

2005 Defense Base Closure and Realignment Commission, *2005 Defense Base Closure and Realignment Commission Report*, September 2005.

AF/XPPE, FY06PB_Mar05_acftmsls3.xls, AF Program Data System, 2005.

AF/XOOTF, Flying Hours.xls, spreadsheet, 2004.

Amouzegar, Mahyar A., Lionel A. Galway, and Amanda B. Geller, *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance*, Santa Monica, Calif.: RAND Corporation, MR-1431-AF, 2002. As of November 25, 2007:
http://www.rand.org/pubs/monograph_reports/MR1431/

Ballou, R. H., and J. M. Masters, "Facility Location Commercial Software Survey," *Journal of Business Logistics*, Vol. 20, No. 1, 1999.

BRAC Report—see 2005 Defense Base Closure and Realignment Commission.

Cohen, I. K., T. Lippiatt, R. Richter, and R. J. Hillestad, *An Evaluation of the Performance of the PACAF Centralized Intermediate Logistics Concept*, Santa Monica, Calif.: RAND Corporation, 1977. Not available to the general public.

Dahlman, Carl J., Robert Kerchner, and David E. Thaler, *Setting Requirements for Maintenance Manpower in the U.S. Air Force*, Santa Monica, Calif.: RAND Corporation, MR-1436-AF, 2002. As of November 25, 2007:
http://www.rand.org/pubs/monograph_reports/MR1436/

Drezner, Zvi (editor), *Facility Location: A Survey of Applications and Methods*, New York, N.Y.: Springer-Verlag New York, 1995.

Excel Management Systems, *Propulsion Requirements System (PRS) End User Manual, V 4.0A*, U.S. Air Force, Air Force Materiel Command, 2000.

Feinberg, Amatzia, Eric Peltz, James Leftwich, Robert S. Tripp, Mahyar Amouzegar, Russell Grunch, John Drew, Tom LaTourrette, and Charles R. Roll, Jr., *Supporting Expeditionary Aerospace Forces: Lessons From the Air War Over Serbia*, Santa Monica, Calif.: RAND Corporation, 2002. Not available to the general public.

Feinberg, Amatzia, Hyman L. Shulman, Louis W. Miller, and Robert S. Tripp, *Supporting Expeditionary Aerospace Forces: Expanded Analysis of LANTIRN Options*, Santa Monica, Calif.: RAND Corporation, MR-1225-AF, 2001. As of November 25, 2007:
http://www.rand.org/pubs/monograph_reports/MR1225/

Fisher, Rolland R., W. W. Drake, J. J. Delfausse, A. J. Clark, and Al Buchanan, *The Logistics Composite Model: An Overall View*, Santa Monica, Calif.: RAND Corporation, RM-5544-PR, 1968.

Geller, Amanda B., David George, Robert S. Tripp, Mahyar A. Amouzegar, and Charles Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Analysis of Maintenance Forward Support Location Operations*, Santa Monica, Calif.: RAND Corporation, MG-151-AF, 2004. As of November 24, 2007:
http://www.rand.org/pubs/monographs/MG151/

Garza, Florencio, Lantirn.xls, ACC/LGMA, January 18, 2005.

General Electric, "Aviation: Comparison Chart—Military Turbo-Fans," 2007. As of November 19, 2007:
http://www.geae.com/engines/military/comparison_turbofan.html

Headquarters Air Combat Command (HQ ACC), Directorate of Plans and Programs, Manpower and Organization Division (XPM), *Statement of F-16 Block 40 Aircraft Maintenance and Munitions Manpower*, Langley AFB, Va., August 2003.

Headquarters ACC/XPM, *Statement of F-16 Block 40 Aircraft Maintenance and Munitions Manpower*, Langley AFB, Va., August 2003.

Headquarters U.S. Air Force (HQ USAF/ILGD), CIRF CONOPS Transportation Computation Chart, spreadsheet, 2004.

Headquarters U.S. Air Force (HQ USAF), Deputy Chief of Staff for Installations and Logistics, Maintenance Management Division (ILMM), *Centralized Intermediate Repair Facility CIRF Test Report*, Washington, D.C.: Pentagon, June 2002.

Hillestad, Richard J., *Dyna-METRIC: Dynamic Multi-Echelon Technique for Recoverable Item Control*, Santa Monica, Calif.: RAND Corporation, R-2785-AF, July 1982. As of November 24, 2007:
http://www.rand.org/pubs/reports/R2785/

Lynch, Kristin F., John G. Drew, Robert S. Tripp, and Charles Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Lessons from Operation Iraqi Freedom*, Santa Monica, Calif.: RAND Corporation, MG-193-AF, 2005. As of November 24, 2007:
http://www.rand.org/pubs/monographs/MG193/

Mapquest, homepage, undated. As of June 10, 2008:
http://www.mapquest.com/

Massey, Gary, Selected_maint_auths4.xls, August 23, 2004.

McIntosh, C. R., FY04 F100F110TF34 BSL Goals CA CONUS.xls, OC-ALC/LR, August 30, 2004a.

———, Net Serviceable/Allocated BSL, January 2003–November 2004, OC-ALC/LR, 2004b.

———, RAND F100.ppt briefing, OC-ALC/LR, 2004c.

———, TF34 briefing, OC-ALC/LR, 2004d.

———, CIRF F100F110GreenMetrics.ppt, January 2003–November 2004, OC-ALC/LR, 2005a.

———, CIRF F100F110Metrics.ppt, January 2003–November 2004, OC-ALC/LR, 2005b.

———, F110 WW ENMCS%, January 2003–November 2004, OC-ALC/LR, 2005c.

———, F100 WW ENMCS%, January 2003–November 2004, OC-ALC/LR, 2005d.

Mills, Patrick, and Amatzia Feinberg, *Supporting Expeditionary Aerospace Forces: Evaluation of the RAMPOD Database*, Santa Monica, Calif.: RAND Corporation, DB-318-AF, 2001. As of November 25, 2007:
http://www.rand.org/pubs/documented_briefings/DB318/

Northrup Grumman, "AN/ALQ-131(V): Combat Success . . . Past, Present and Future," Northrup Grumman Electronic Systems, undated. As of November 25, 2007:
http://www.es.northropgrumman.com/ASD/brochures/ALQ131.pdf

Office of Management and Budget, "Real Treasury Interest Rates," 2004. As of November 16, 2007:
http://www.whitehouse.gov/omb/circulars/a094/dischist-2007

———, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs Appendix C*, Circular No. A-94, 2006.

Office of the Under Secretary of Defense (Comptroller), Fiscal Year 2006 Department of Defense Military Personnel Composite Standard Pay and Reimbursement Rates, undated. As of June 10, 2008:
www.defenselink.mil/comptroller/rates/fy2006/2006_k.pdf

Peltz, Eric, Hyman L. Shulman, Robert S. Tripp, Timothy Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: An Analysis of F-15 Avionics Options*, Santa Monica, Calif.: RAND Corporation, MR-1174-AF, 2000. As of November 25, 2007:
http://www.rand.org/pubs/monograph_reports/MR1174/

Pratt Witney, "F100: The Power Plant of Choice," 2007. As of November 23, 2007: http://www.pw.utc.com/vgn-ext-templating/v/indexjsp?vgnextrefresh=1&vgnextoid=227f07b06f5eb010VgnVCM1000000881000aRCRD

Rappold, J. A., and B. D. Van Roo, "Designing Multi-Echelon Service Parts Networks with Finite Repair Capacity," *European Journal of Operations Research*, DOI: 10.1016/J.EJOR.2008.08.006.

Raytheon Company, "AN/ALQ-184 Self-Protect ECM Pod," 2005. As of November 20, 2007:
http://www.raytheon.com/products/stellent/groups/sas/documents/asset/alq184.pdf

Rodrigues, Gonçalo, "A Date Module," ActiveState Programmer Network, last updated October 25, 2001. As of November 23, 2007:
http://aspn.activestate.com/ASPN/Cookbook/Python/Recipe/117215

SAF/FMBOP, AFI 65-503, Cost Factors, Attachments A19-2, FY2004 Standard Composite Rates by Grade, Military, undated.

Sherbrooke, Craig C., "METRIC: A Multi-Echelon Technique for Recoverable Item Control," *Operations Research*, Vol. 15, No. 6, 1968, pp. 985–110.

Slay, F. Michael, *VARI-METRIC: An Approach to Modeling Multi-Echelon Resupply when the Demand Process is Poisson with a Gamma Prior*, McLean, Va.: Logistics Management Institute, AF301-3, 1984.

Sleptchenko, A., M. C. van der Heijden, and A. van Harten, "Effects of Finite Repair Capacity in Multi-Echelon, Multi-Indenture Service Part Supply Systems," *International Journal of Production Economics*, Vol. 79, 2002, pp. 209–230.

Strong, Robert, "FY2005 Actuarial Removal Interval Worksheet," MSG/SLW, FY2005.

U.S. Air Force, "Readiness Based Leveling (RBL) Production System Process Description," HQ AFMC/LGI Directorate of Item Management, Air Force Materiel Command, Wright-Patterson AFB, Ohio, April 2004.

U.S. Air Force, TO 00-25-254-1, *Comprehensive Engine Management System: Engine Configuration, Status, and TCTO Reporting Procedures*, Automated Technical Order System, 2001.

U.S. Department of Defense, Military Surface Deployment and Distribution Command, "DoD Standard Transit Time Guide—Truckload," February 28, 2006. As of November 19, 2007:
http://www.sddc.army.mil/sddc/Content/Pub/36017/28Feb06_TTC%20II%20TransitTimeGuide.pdf

U.S. Government, "Department of Defense (DoD) Airlift Rates: Passenger and Cargo Channel Rates, Effective: 01 Oct 05 through 30 Sep 06," 2005. Not available to the general public.